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Business Case for Energy Efficiency in Support of Climate Change Mitigation, Economic and Societal Benefits in the Republic of Korea

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June 8, 2012

This work was supported by the International Copper Association through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

EXECUTIVE SUMMARY

This study seeks to provide policymakers and other stakeholders with actionable information towards a road map for reducing energy consumption cost-effectively. We focus on individual end use equipment types (hereafter referred to as *appliance groups*) that might be the subject of policies - such as labels, energy performance standards, and incentives - to affect market transformation in the short term, and on high-efficiency technology options that are available today.

As the study title suggests, the high efficiency or *Business Case* scenario is constructed around a model of cost-effective efficiency improvement. Our analysis demonstrates that a significant reduction in energy consumption and emissions is achievable at *net negative cost*, that is, as a profitable investment for consumers. Net savings are calculated assuming no additional costs to energy consumption such as carbon taxes. Savings relative to the base case as calculated in this way is often referred to as "economic savings potential".

The economy of the Republic of Korea (Korea) is energy intensive and dependent on energy imports. Korea is the 10th largest energy consuming nation in the world and it spent 17~~2~~2 billion[NDB1] dollars on energy imports in 201~~0~~1[1]~~, [12] nearly a third of its total imports~~. Since 1992 energy supply restrictions and price pressures have spurred national energy efficiency programs to reduce the potential burden of rising energy costs. Korea's economy is one of the fastest growing developed economies in terms of GDP growth, and is one of the most resilient in adverse conditions. In the residential sector, this advanced economic level is reflected in the high ownership rates of electronic devices and appliances, though residences are small by U.S. or E.U. standards. Korea's commercial building and industrial sectors, well-known for their high-end technology, generate substantial energy needs for the country. Sixty percent of the nation's final energy demand comes from industrial energy consumption.

The Republic of Korea has historically faced the challenge of energy efficiency, and as it continues to do so the country helps create an encouraging energy future for itself. First established in 1992, the Energy Efficiency Label and Standard Program (EELSP) applies a label requiring 35 different types of products meet a Minimum ~~Efficiency~~ Energy Performance Standard (MEPS) [13][NDB4]and indicate efficiency on a 5 grade scale. Additionally, a voluntary high-efficiency appliance certification program has been running since 1996, and a mandatory stand-by power labeling program has been in effect since 1999. To aid these programs, the country has successfully run market transformation techniques from financing programs to building codes to procurement requirements. While this activity has helped Korea mitigate emissions, this study indicates savings potential can still be captured from currently available technologies. Potential impacts of this adoption include:

Energy savings:

- 7.3 billion kWh per year in 2020
- 19 billion kWh per year in 2030

[1]http://www2.korea.kr/expdoc/viewDocument.req?id=32056&pWise=subRight

- A total of 160 billion kWh cumulatively through 2030

Cumulative greenhouse gas emissions mitigation:

- 56 million metric tons of CO_2 through 2030

Financial impacts to consumers through 2030:

- Equipment investment of 8.2 billion USD
- Energy bill savings of 17~~8~~ billion USD
- Net savings of 8.5~~11~~ billion USD

The approach of the study is to assess the impact of short-term actions on long-term impacts. "Short-term" market transformation is assumed to occur by 2015, while "long-term" energy demand reduction impacts are assessed in 2030. In the intervening years, most but not all of the equipment studied will turn over completely. The 15-year time frame is significant for many products, in the sense that delay of implementation postpones economic benefits and mitigation of emissions of carbon dioxide. Such delays would result in putting in place energy-wasting technologies, postponing improvement until the end of their service life, or potentially resulting in expensive investment either in additional energy supplies or in early replacement to achieve future energy or emissions reduction targets.

The Korean government has set a National Strategy for Green Growth, a program pairing goals for national economic stimulus and climate change mitigation. In addition to massive investment in 'green' technologies, in 2009 the government of the Republic of Korea committed to reduce carbon emissions to 30% below expected 2020 levels[2]. The Korean government has made explicit its hopes to move rapidly to a clean energy economy, and transition quickly past fossil fuel dependence. Such aspirations require deep commitments, such as Korea's legislation in April 2012 to start a carbon emissions trading program. Korea's approaches to decreasing the energy demand through energy efficiency promises to aid its green growth goals, and implementation of cost-effective technologies for all new equipment in the buildings sector is complementary to these goals, as they would provide a mechanism to sustain carbon and energy intensity reductions in the medium and long term.

The *Business Case* concentrates on technologies for which cost-effectiveness can be clearly demonstrated. The appliance groups studied are:

[2] http://online.wsj.com/article/SB125842928229651665.html

Residential End Uses
Gas Boilers
Refrigerators
Freezers
Split Room Air Conditioners
LCD Televisions

Commercial and Industrial End Uses
Commercial Refrigerators
Industrial Three Phase Motors

Energy savings and greenhouse gas emissions mitigation for these appliance groups are summarized in table ES-1.

Table ES- 1 – Energy Savings and Pollutant Mitigation by Appliance Group

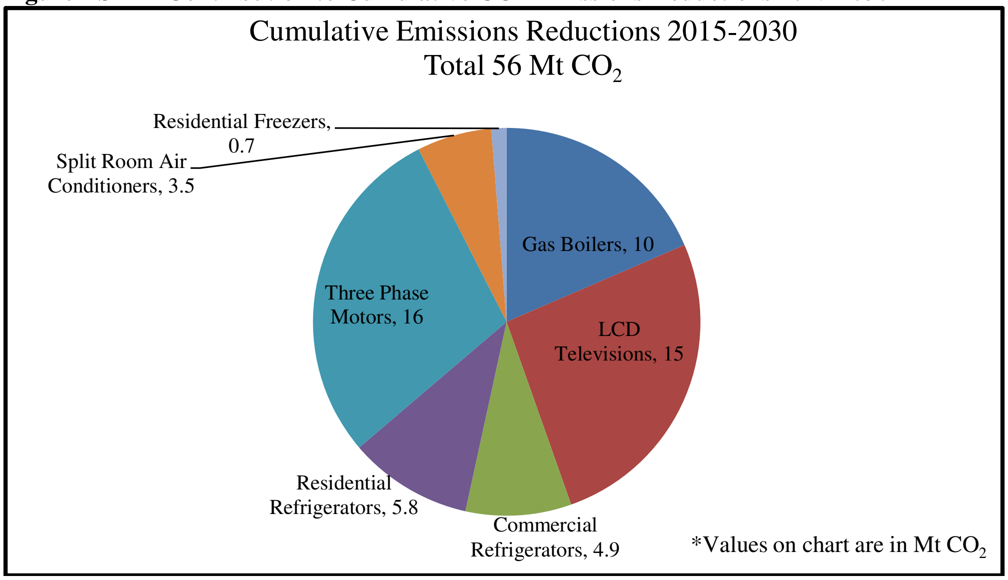
	Final Energy Savings			Emissions Mitigation		
	In 2020	In 2030	Through 2030	In 2020	In 2030	Through 2030
Appliance Group	TWh			Mt CO_2		
Gas Boilers	2.3	5.7	51	0.47	1.2	10
Three Phase Motors	1.4	5.5	40	0.6	2.1	16
LCD Televisions	1.7	3.7	36	0.73	1.4	15
Residential Refrigerators	0.65	1.6	14	0.27	0.62	5.8
Commercial Refrigerators	0.63	1.1	12	0.27	0.44	4.9
Split Room Air Conditioners	0.41	0.90	8.6	0.17	0.35	3.5
Residential Freezers	0.079	0.19	1.7	0.033	0.076	0.71
Total	**7.3**	**19**	**160**	**2.6**	**6.2**	**56**

Note: Values do not add up to totals due to rounding.

Since the study includes only appliance groups for which cost-effectiveness can be clearly demonstrated, the benefits determined represent only a subset of the economy-wide potential. Specifically, transportation appliance groups and industrial processes technologies are not covered, because data sufficient to include them were not possible to collect within the scope of the research. Likewise, the study does not include system approaches such as smart grids. These approaches to efficiency may have important impacts but the calculation of costs and benefits is not as straightforward as for individual pieces of equipment. In addition, the technologies analyzed represent a snapshot of what is currently on the market. Technological innovations are certain to occur over the coming decades, and these will likely present new opportunities for efficiency improvement, and exert downward pressure on costs.

Efficiency measures are determined to be cost-effective if the cost of conserved energy associated with them is less than the consumer's energy price, that is, the amount saved in energy bills is greater than the initial investment. The *Business Case* scenario is generated by identifying the *maximum efficiency improvement for which cost of conserved energy is lower than utility energy prices*. The relative contribution to cumulative emissions for each appliance group is shown in Figure ES- 1.

Figure ES- 1 – Contribution to Cumulative CO2 Emissions Reductions 2015-2030



Several conclusions can be drawn from Table ES- 1and Figure ES- 1. First, emission reduction potential is mostly composed of savings from the residential sector. Only motors and refrigerators were available for the commercial and industrial sector, respectively, which is reflective of the limited data. The largest potential exists for three-phase motors, LCD televisions and gas boilers, which could provide about 127 TWh of electricity demand reduction and 41 Mt of CO_2 over the forecast period. Motors savings comes from adopting IE3 level motors by 2017. The Korean government has set this efficiency level as a national target, and it is a goal which we have found to be cost-effectively achievable. Savings in LCD televisions is possible due to dimming enhancements and improved optical films used in the screen. Gas boiler savings come from wide-spread adoption of condensing gas boilers. Korean ~~boasts one of the world's most efficient~~ residential refrigerators, ~~markets, even~~ at 21% of household power consumption (KEMCO, 2012c), ~~refrigerators still~~ offer substantial energy savings at the marginal improvements we identified as cost effective. [15][NDB6]Commercial refrigerators have been labeled since 2010, and the second highest efficiency grade is cost effective for both refrigerator and refrigerator-freezers. [17][NDB8]Combined, refrigerators offer about 26 TWh of energy savings in Korea. The remaining savings comes from improvements in split room air conditioners over 4kW in cooling capacity and from a 44% increase in residential freezer efficiency.

Table ES- 2 – Cumulative Financial Impacts of Efficiency Improvement

Appliance Group	Cumulative Financial Impacts (Discounted @ 3% DR)		
	Equipment Cost	Operating Cost	NPV
	Billions USD		
Three Phase Motors	**0.94**	-3~~4~~.7~~0~~	**2~~3~~.7~~1~~**
Gas Boilers	**3.3**	-5.4	**2.0**
LCD Televisions	**1.1**	-2.8	**1.7**
Commercial Refrigerators	**0.46**	-1.1~~6~~	**0~~1~~.66~~1~~**
Residential Refrigerators	**1.2**	-2.3	**1.0**
Split Room Air Conditioners	**0.93**	-1.2	**0.30**
Residential Freezers	**0.22**	-0.28	**0.060**
Total	**8.2**	**-17~~18~~**	**~~9.3~~8.5**

The analysis shows that cost-effective efficiency improvement could yield very significant financial benefits to Korean consumers. Table ES- 2 shows positive net savings for all appliance groups, which is not surprising, since the target efficiency levels were constructed to be cost-effective. The table shows that cost-effective efficiency improvements require an investment of 8.2 billion USD over the next 20 years, but these investments will provide a return of over ~~nearly~~ 200~~15~~ percent over the same period through reduced operating costs. This results in a discounted net savings of 8.5~~9.3~~ billion dollars, assuming a discount rate of 3-percent. The net savings is of order of two hundred dollars per capita.

Of the appliance groups studied, ~~LCD Televisions~~ gas boilers require the largest investment at ~~2.5~~3.3 billion USD, but its payoff of 5.4~~2~~ billion USD is two thirds more than ~~double~~ the investment. Residential refrigerators and ~~gas boilers~~ LCD televisions are the next largest investments, and generate 5.1 billion USD of savings. Phasing in IE3 motors is extremely cost effective, with a payoff nearly four~~ive~~ times as high as the required investment.

1. Introduction

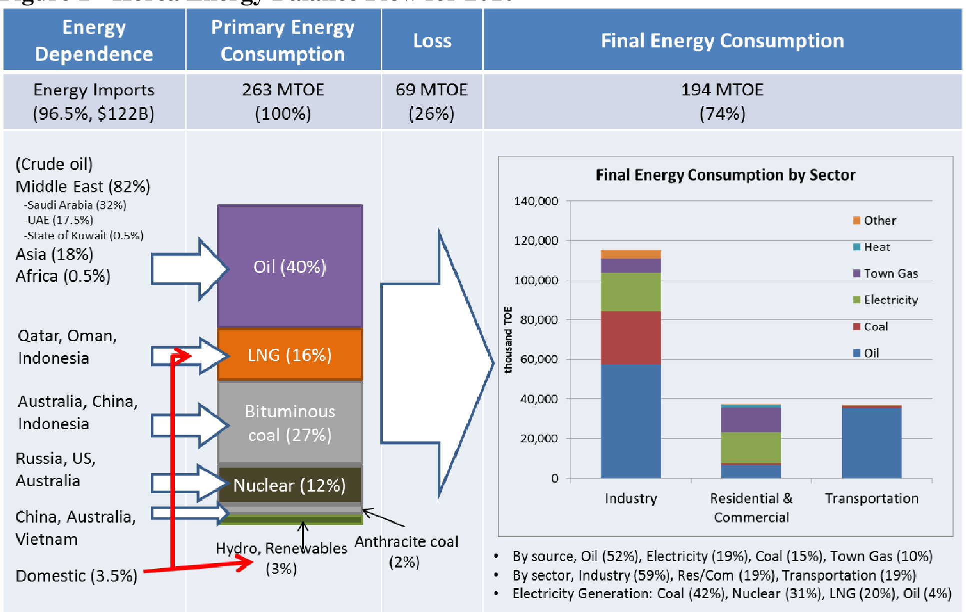
This study seeks to provide policymakers and other stakeholders with actionable information towards a road map for reducing energy consumption in the most cost-effective way. A major aspect of the current study is the focus on individual equipment types that might be the subject of policies - such as labels, energy performance standards, and incentives - to affect market transformation in the short term, and on high-efficiency technology options that are available today.

The approach of the study is to assess the impact of short-term actions on long-term impacts. “Short term” market transformation is assumed to occur by 2015, while “long-term” energy demand reduction impacts are assessed in 2030. In the intervening years, most but not all of the equipment studied will turn over completely. The 15-year time frame is significant for many products however, indicating that delay of implementation postpones impacts such as net economic savings and mitigation of emissions of carbon dioxide. Such delays would result in putting in place energy-wasting technologies, postponing improvement until the end of their service life, or potentially resulting in expensive investment either in additional energy supplies or in early replacement to achieve future energy or emissions reduction targets.

National Energy Consumption

The Republic of Korea is the world’s sixth largest importer of petroleum and the second largest importer of liquefied natural gas (LNG) (UNEP 2010). In 2010, Korea imported about 97% of its energy resources from other countries, spending $122 billion (MKE and KEEI 2011). The industrial sector accounts for about 60% of the final energy consumption, and the residential and commercial sector combined with the transportation sector represent about 20%. Electricity accounts for about 20% of the final energy consumption (see Figure 1).

Figure 1 - Korea Energy Balance Flow for 2010



Source: MKE and KEEI 2011 MTOE: million tonnes of oil equivalent

Given such high energy dependence, Korea is very vulnerable to fluctuations in international energy prices and supplies. In addition, due to the rapid industrialization and urbanization, Korea's greenhouse gas (GHG) emissions have increased significantly during the past 15 years (UNEP 2010). According to an OECD report (Jones and Yoo 2010), Korea's GHG emissions in 2005 (594 Mt CO_2) accounted for 1.3% of global emissions, ranking the country as the 15th-largest emitter in the world and ninth among the OECD countries. Korea's emissions almost doubled between 1990 and 2005, and 83% of the increase occurred by 2000. Korea's energy intensity[3] was a quarter above the OECD average in 2008 and the fourth highest in the OECD. During the period of rapid economic growth between 1971 and 1997, energy use in the country increased at an 8.8% annual rate, led by the commercial and transport sectors. Energy intensity, which was 42% below the OECD average in 1971, peaked during the 1997 crisis[4]. After the crisis, the industrial and residential sectors have been largely responsible for the increase in energy consumption. Figure 2 shows the historical energy intensity trends of Korea, Japan, the U.S. and the average of OECD countries.

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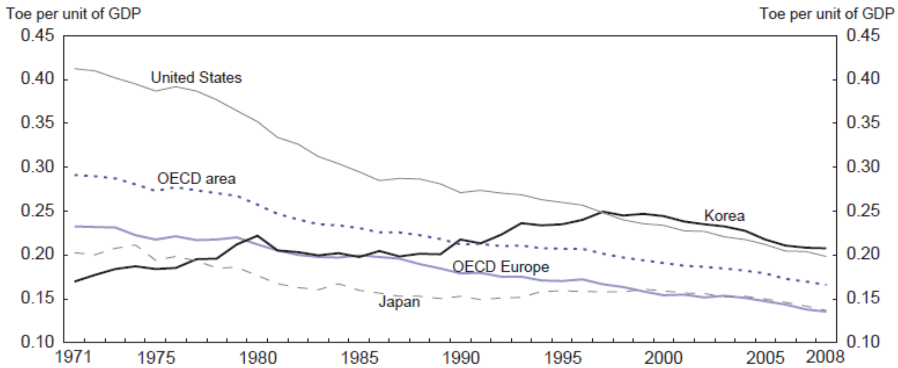
[3] Energy intensity, defined as total primary energy supply (TPES) divided by GDP, is affected by many indirect factors such as climate, geography, travel distance, home size and manufacturing structure.

[4] On October 1997, the Korean Stock Exchange began to plunge followed by a sharp fall of the Korean Won against dollar. Although the changes occurring in Korea were seen as a part of a regional contagion effect deriving from the Southeast Asian crisis, Korea's foreign reserves were nearly depleted by November 21. The government determined to have emergency loan from the International Monetary Fund (IMF) to and to prevent the total collapse of the economy and overcome the difficulties in the financial and currency markets (Asianinfo 2000).

Figure 2 - Historical Energy Intensity Trends of Korea, Japan, US and OECD countries



Source: Jones and Yoo 2010 TOE: tonne(s) of oil equivalent

1.1. Efficiency Policy

The Ministry of Knowledge Economy (MKE) and Korea Energy Management Corporation (KEMCO) are the key organizations in designing and implementing policy measures.

Rational Energy Utilization Act (Since 1979)

Following the oil shocks of the 1970s, the Korea government enacted the Rational Energy Utilization Act in 1979. The act has been revised several times since, notably in 2002, 2003 and 2008. The major revisions include the following (IEA 2010b):

- 2002 revision - introduction of Corporate Average Fuel Efficiency (CAFE) standards, voluntary agreements with industry, and promotion of energy efficiency labels
- 2003 revision - measures to reduce GHG emissions, on top of improving the efficient use of energy, including voluntary agreements to encourage Energy Service Companies (ESCOs) and other companies to register their emission reductions with the government.
- 2008 revision - implementation of various energy management measures such as energy audit, ESCOs and certification of energy-efficient equipment.

Climate Change Mitigation

In August 2009, the government presented three options that target GHG emissions reduction by 21%, 27% or 30% respectively, compared to the 2020 projection which is based on a business as-usual" (BAU) scenario of a 36.9% increase between 2005 and 2020. The three options imply an 8% increase in emissions, no change or a 4% reduction, respectively, compared to the 2005 baseline. The Korean Cabinet selected the most ambitious option of a 30% reduction by 2020 relative to the BAU baseline.

Five-Year Plan for Green Growth (2009-2013)

In July 2009, the Korean government adopted a Five-Year Plan for Green Growth[5] that serves as a medium-term plan for implementing "low-carbon, green growth" announced a year earlier. The plan has three key objectives; 1) creation of new sustainable growth pathways through low-carbon industries, 2) securing climatic and environmental sustainability, and 3) contribution to the international efforts to mitigate climate change (UNEP 2010). The plan calls for spending 2% of GDP per year over the five years (total 107 trillion won, approximately 97 billion dollars). Public construction projects focused on improvements in land, water, and transport, account for more than half of the total budget. Investment in R&D for green technologies, for both energy sources and energy efficiency, account for 12% of the budget (Jones and Yoo 2010).

Energy efficiency measures in the plan include a negotiated agreement between the government and large energy-consuming companies in order to reduce energy consumption, new standards to increase fuel efficiency for vehicles, a ban on sales of incandescent lights, and the promotion of light emitting diode (LED) lamps (UNEP 2010). Overall, this set of measures for the development and dissemination of hybrid electric vehicles, the adoption of stringent standards on fuel efficiency, energy conservation and green buildings, and the promotion of investment in energy conservation facilities are expected to increase total energy efficiency from 0.317 ton of oil equivalent (TOE) per USD in 2009 to 0.290 TOE per USD in 2013, and to 0.233 TOE per USD in 2020 (UNEP 2010).

1.2. Appliance Efficiency Programs

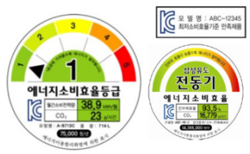
1.2.1. Regulatory Actions

Energy Efficiency Standards and Labeling Programs

The Korean government has implemented three energy efficiency programs; the Energy Efficiency Label and Standard Program (EELSP), the High-Efficiency Appliance Certification Program, and the e-Standby Program. Table 1 shows a summary of the three energy efficiency programs (MKE and KEMCO 2011).

[5] This initiative revives the practice of five-year plans which were implemented between 1962 and mid-1990s for economic development (Jones and Yoo 2010).

Table 1 - Summary of Three Major Energy Efficiency Programs[19][NDB10]

Energy Efficiency Label and Standard Program	High-Efficiency Appliance Certification Program	e-Standby Program
		
· 1992 to present · Mandatory · Rating 1 (most efficient) to Rating 5 (+ MEPS) · 35 items (over 2~~0~~6,000 models)	· 1996 to present · Voluntary · Designed for commercial buildings and industry equipment · 39~~41~~ items	· 1999 to present · "Energy Boy" (voluntary) · Warming Label (mandatory) · 22 items (over 9,000 models)
· Home appliances, lightings, motors, automobiles, etc. · Public procurement and low-interest loans to qualified manufacturers, available for some Rating 1-qualified products	· LEDs, fans, transformers, etc. · Rebates, public procurement, tax allowances, low-interest loans available for eligible products	· Computers, monitors, set-top boxes, and office equipment, etc. · Fine of less than $5000 for violation · Public procurement, low-interest loans available for purchasing and manufacturing Energy Boy labeled products

Source: MKE & KEMCO 2011

The Energy Efficiency Label and Standard Program (EELSP) has run since 1992 with an aim of energy efficiency improvement in key products including appliances and vehicles that account for majority of energy consumption. The products subject to the program are required to carry an energy efficiency label that indicates one of the five energy-efficiency grades. Products not qualifying for efficiency ratings may not be sold in the market, hence serving as a Minimum Energy Performance Standard (MEPS). The High Efficiency Appliance Certification Program was designed for energy efficiency improvement in commercial buildings and industrial equipment. The government awards labels to products that meet the required efficiency levels. Since 1999 the e-Standby program has promoted energy savings in standby-mode, targeting standby power consumption to less than 1 Watt by 2010.

Mandatory Use of High Energy-Efficiency Appliances in Public Organizations

Based on "Directive on Rational Energy Utilization Implementation to Public Organizations" by MKE, all public organizations when making new purchases or replacing existing appliances must procure high-efficiency-certified appliances, Energy Boy labeled products, or energy efficiency grade 1 qualified products, as long as there are no compelling reasons to do otherwise. In addition, device and software that enable users to save standby-mode power consumption must be installed in public offices (MKE and KEMCO 2011).

Building Codes

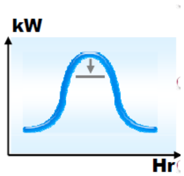
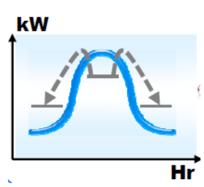
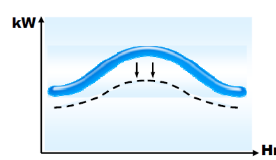
In accordance with the “Energy Saving Design Standards for Buildings” from the Ministry of Land, Transport and Maritime Affairs, specific types of buildings - apartments, townhouses, and educational facilities with floor space of 3,000 m^2 (32.3 thousand ft^2) or more – are required to install high-efficiency-certified electric transformers, high-efficiency certified or efficiency grade 1 lighting equipment, and automatic standby-mode power block outlets. In addition, the buildings are recommended to install energy efficient LED guide lights, gas boilers, freezers, heat-recovery ventilators, three-phase electric motors, and home gateway system (MKE and KEMCO 2011).

1.2.2. Voluntary Programs

Energy Efficiency Programs in Demand Side Management (DSM)

KEMCO, Korea Electric Power Corporation (KEPCO), and Korea Power Exchange (KPX~~E~~) [111][NDB12]are the key organizations conducting electricity demand-side-management (DSM) programs. DSM includes incentives for energy-efficient products as well as for load management programs. DSM energy efficiency programs offers rebates to installers or distributors of high-efficiency-qualified products, including LEDs, automatic lighting control systems, motors, inverters, transformers, among other end-uses. However, appliances are not included yet. Table 2 shows how these different DSM techniques affect peak load. Factoring in the effects of DSM programs, KEMCO estimates demand will increase from 67 gigawatts [GW] in 2009 to 82 GW in 2022, with an average annual growth rate of 1.9% in electricity consumption. Peak demand with DSM is expected to 12% less than the base case without DSM (KEMCO 2009).

Table 2 - Summary of DSM Programs

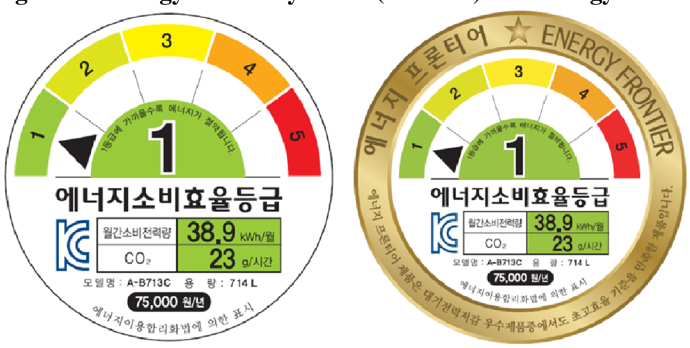
Load Management		Energy Efficiency
		
· Peak demand adjustment programs · Voluntary electricity savings · Remote control system for HVAC · Demand controller	· Cool storage system	· Lighting (LEDs) · Automatic lighting control system · Induction motors · Inverters · Transformers

Source: KEMCO 2009

Energy Frontier

In September 2011 MKE announced the Energy Frontier program, which sets mid-term energy efficiency goals in key appliances at 30-50% more efficient than grade 1 (most efficient). It also provides incentives to manufacturers (MKE and KEMCO 2011). The first phase of the program includes only four major appliances; televisions, refrigerators, air conditioners, and clothes washers. Energy Frontier provides incentives to those who have achieved the target efficiency within a specified period, e.g., in three years.

Figure 3 - Energy Efficiency Label (Grade 1) and Energy Frontier Label



Source: MKE and KEMCO 2011

1.2.3. Market Transformation Programs for Motors and Lighting

Motors

Motors account for 60% of total power consumption in the country, and three-phase electric motors as a single unit of equipment represent 40% of the total consumption (MKE and KEMCO 2011). The government has supported development of high efficiency motors since 2005, and recently determined to implement standards for IE3 motors. In September 2011, MKE announced a plan to provide incentives and technical support to development of IE3 motors.

From 2015 onward, motors sold in the market must be qualified for the standards for premium efficiency motors (IE3), though they are gradually phased in according to motor capacity. Mandatory MEPS for premium efficiency motors (IE3) will be applied to large capacity motors (37-~~200kW~~-375kW) in 2015, [113][NDB14]medium motors (15-37kW) in 2016 and small motors (0.75-15kW) in 2017, as shown in Table **3**. From 2012 through 2014, premium efficiency motors will be supplied to the market through a pilot project. To this end, the *Motor Challenge* program will be implemented, which aims to promote manufacturing, sales and technology development of IE3 motors through financial support. Additional support plans for commercialization of IE3 motors with less than 37 kW are under consideration, because those motors are produced mainly by small- and medium-sized companies.

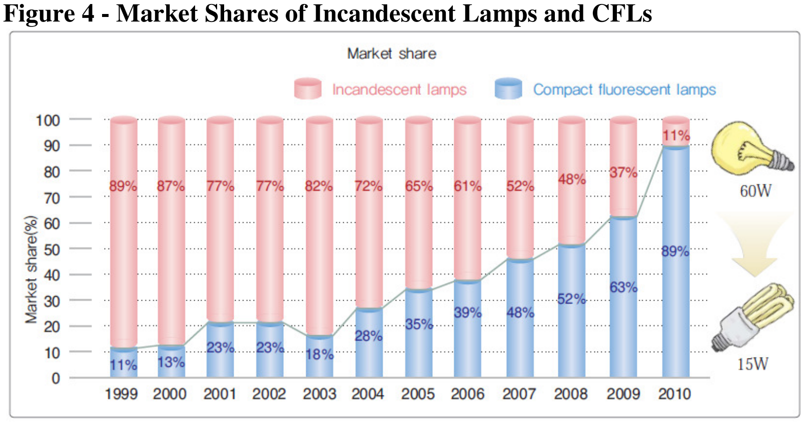
Table 3 - Market Transformation Plan for 3-phase Electric Motors

	Apr 1, 2012-Dec 31, 2014	Jan 1, 2015~	Jan 1, 2016~	Jan 1, 2017~
Premium Efficiency (Trial)	Promotion of premium efficiency motors (financial and technical assistance)	-	-	-
MEPS (Mandatory)	-	Large (37-~~200kW-~~375kW)[115][NDB16]	Medium (15-37kW)	Small (0.75-15kW)
Size of Manufacturer	-	Large		Small and medium

Source: MKE and KEMCO 2011

Public campaigns and financial subsidies have increased the market share of compact fluorescent lamps (CFLs) from 11% in 1999 to 89% in 2010 (MKE and KEMCO 2011). On December 15th 2008, the National Energy Savings Implementation Committee determined to phase out low efficiency incandescent lamps from the market. MEPS for lightings will be set to 20 lumens per watt [lm/W] from 2014 onward, so that the 10-15 lm/W incandescent lamps will no longer be sold in the market.

Figure 4 - Market Shares of Incandescent Lamps and CFLs



Source: MKE & KEMCO 2011

Distribution of LEDs

The MKE announced the "LED Lights 15/30 Dissemination Project", which aims to increase the share of LED lights to 30% by 2015, resulting in savings of 4 million TOE, equivalent to 1.5 billion USD (MKE and KEMCO 2011). LED lights will be immediately supplied for traffic lights, guiding lights, and replacement of halogens.

Table 4 - Market Transformation Plan for LEDs

Types	’07	’08	’09	’10	’11	’12	’13	’14	’15
Traffic lights	Certification, Regional energy project support				MEPS →				
Guiding lights, halogen replacements	Certification, Pilot project		Financial rebate					MEPS →	
Replacing incandescent lamps/channel displays			Certification	Pilot project		Financial rebate			
Replacing fluorescent lamps and street lights				Certification	Pilot project		Financial rebate		

Source: MKE and KEMCO 2011

1.2.4. Financial Incentives

The Korean government has been implementing various policies to accelerate market penetration of energy efficient appliances. The policies include rebates, tax allowances on energy efficiency investments, rational utilization energy subsidies, and financial support for testing fees. Energy efficient appliances eligible for these incentives include Energy Efficiency Label (Grade 1) qualified appliances, High-Efficiency certified equipment, and Energy Boy labeled items, i.e., with less than 1 W in standby-mode power (see Table 5).

Table 5 - Incentives Designed to Support Energy Efficiency S&L Programs

Type	Requirements
Rebates	• Available for high-efficiency-certified equipment and appliances: inverters, freezers, LEDs (emergency light, hallway light, internal/external converters)
Tax benefits	• Jan 2005 – Dec 2011 (tax waiver , 10% of total investment cost, from income or corporate tax) • LED lightings, lighting equipment with automatic luminous intensity control, heat recovery ventilators
Low-interest loans	• Available for Energy Efficiency Label (grade 1), high-efficiency-certified products, and Energy Boy labeled products (e-Standby) • Installation: up to 10 million USD per year • Production by small and medium manufacturers: up to 5 million USD per year
Testing fee Waiver	• KEMCO provides financial support to small- and medium-sized manufacturers for testing fees subject to energy efficiency S&L programs.

Source: MKE & KEMCO 2011

Counter-incentives and Carbon Point Programs

In addition to DSM energy efficiency programs and the above incentives, the Korean government has implemented other types of incentives, e.g., counter-incentives for high energy consuming appliances and downstream incentives for high efficiency appliances. In 2010, Korea introduced a ~~6.5~~ 5.0 % tax penalizing high-consuming or large-capacity appliances (~~MSF~~ MOSF 2010, KEMCO 2012d). The appliances covered by this tax system include TVs bigger than 40 inches, refrigerators that consume more than 40 kWh per month, large fans, drum washers that consume more than 720 kWh per month, and air conditioners that consume more than 370 kWh per month. The tax is effective from April 2010 to December ~~2012~~ 2015, and the tax revenues will be used to support social welfare facilities such as for orphanages to replace outdated appliances with energy efficient ones.[117][NDB18]

The Ministry of Environment (ME) with local governments launched the *Carbon Point* program in October 2008, and MKE and KEMCO launched the *Carbon Cashbag* program in 2009. These programs were designed to provide consumers with incentives for energy savings or purchasing low-carbon-intensity products. In the *Carbon Point* program, operated by the ME and local governments, participants are eligible to receive financial rewards for consuming less-than-average electricity, water and gas over the past 2 years. The savings are measured by the amount of CO_2 reduced, and the participant is accumulates carbon points. One carbon point is equal to 3 won (about $0.27 USD). The points can be redeemed in various forms, such as cash, public transportation cards, or trash bags that include the disposal fee in its price. As of October 2010 a total of 1.5 million households, about 8.8% of all households in Korea, were registered in one of the consumer rewards program. However, participation rates for many regions were below 5% (Ko 2010).

In the *Carbon Cashbag* operated by MKE and KEMCO a consumer can get carbon points on his/her carbon cashbag card, which is based on an existing domestic cashbag program. Unlike the *Carbon Point* program managed by ME, consumers who purchase low-carbon products get carbon credits from manufacturers, retailers, or banks that participate in the *Carbon Cashbag* program, and can then use the points as cash for discount on public transportation, utility charges, appliance purchases, or tickets to cultural events. This is a voluntary program; the participating companies can get benefits from reductions in advertising fees and other public incentives. As of October 2011, 33 companies had been participating in the program with 18 products, 333 sub-products (KEMCO 2011).

2. Energy Demand Scenarios

As the study title suggests, the high efficiency or *Business Case* scenario is constructed around a model of cost-effective efficiency improvement. The point of the study is to demonstrate that a significant reduction in energy consumption and emissions is achievable at a net negative cost, that is, as a profitable investment for society. There are a variety of ways of assessing costs and benefits to society. We chose to focus on the end user's perspective: costs in terms of additional retail equipment prices (capital investments); savings from reduced energy bills (operating costs). Only direct energy savings are included, without valuing non-energy benefits that may also accrue (comfort, productivity, health). Finally, the cost-benefit analysis is made without the elevated effective energy prices that could be implied by carbon taxes, carbon trading schemes or other policies. Savings relative to the base case as calculated in this way is often referred to as "economic savings potential".

A national-level high-efficiency scenario is constructed by assuming that market transformation to high-efficiency technologies will occur by 2015, which is judged to constitute the "short term" by the study, because it considers that five years is sufficient time to achieve market transformation through aggressive policies and stakeholder actions. The study does not model specific actions, which could include mandatory standards, voluntary labeling programs, voluntary agreements by manufacturers, utility demand-side-management programs and others[6].

The target efficiency level chosen is that which *maximizes efficiency while providing a net benefit to consumers*. This is to be contrasted with scenarios which maximize consumer payoff but not necessarily efficiency improvement, or those that include the best available technology ("max tech") without consideration of cost-effectiveness. Consumer cost-benefit analysis is evaluated in terms of cost of conserved energy. Cost of conserved energy (CCE) is the amortized incremental cost of equipment divided by annual energy savings. In other words, it's the additional annual capital investment needed to purchase high-efficiency equipment instead of baseline equipment, divided by the energy savings provided by the investment. This quantity, which has units of USD per unit energy, can be compared to prevailing energy prices to assess

[6] For simplicity the high efficiency scenario assumes 100% of the market will reach the target level in 2015, a structure that closely resembles minimum efficiency performance standards. In the later years of the forecast, the scenario is not highly sensitive to the details of the market transformation.

consumer cost-effectiveness. Technologies with a CCE less than forecast energy prices in 2015 are deemed cost-effective.

A few comments about whether this definition is optimistic or pessimistic are warranted. On one hand, high efficiency technologies are compared to the current baseline technology, even though there may already be a market for higher efficiency equipment, and the average efficiency of the market is constantly improving. This tends to underestimate the baseline forecast and overestimate savings. On the other hand, it likely underestimates the efficiency that will be achievable in a cost-effective way, first of all because technology costs are generally decreasing (according to technological learning rates) and the emergence of new technologies that may not be available for analysis. Therefore, there are two compensating effects not taken into account in the analysis. The results should therefore be taken as representative of the scale of potential improvement, not as a reliable prediction. The methodology is chosen to maximize concreteness and defensibility by relying on technologies that can be justified by actual cost data.

2.1. Literature Review

Some recent examples of studies that have identified potential energy savings from energy efficiency improvements include:

China

- China's appliance standards are estimated to have saved 1.08 EJ during 2006-2008, with refrigerators, air conditioners and televisions contributing the bulk of the savings. (Price et al. 2011)
- (McNeil et al., 2011b) covers 15 end-uses across the residential, commercial, and industrial sectors, with an estimate of potential savings of 8,313 TWh of savings by 2030.
- (Aden 2010) uses lifecycle assessment to show that for buildings in the Beijing area, 80% of energy use and related emissions is due to operations, and about 20% due to materials.
- (Zhou 2010) provides an overview of China's policies on energy efficiency.
- (Fridley 2008) estimates potential savings of 1.2 TWh in 2012 and 16 TWh by 2020 for energy labels on refrigerators in China.

India

- (McNeil et al., 2011c) covers 9 end-uses for the residential, commercial, and industrial sectors, with an estimate of 1,251 TWh of savings by 2030.
- (De la Rue du Can 2009) provides both retrospective and prospective views of energy use in the residential and transport sectors of India.
- (Delio 2009) estimates potential savings from energy efficiency across all sectors in India to be 183 TWh in five years.

Republic of Korea

- (Lee, S.I. and Choi, D.Y. 2010) assessed energy efficiency and estimated energy savings potential in the three largest energy-consuming industries; iron and steel, petroleum chemistry, and non-metallic mineral, over 3 years (2010-2012).

United States

- (McNeil et al., 2011a) covers 14 end-uses for the residential, commercial, and industrial sectors, and estimates 5,754 TWh of savings by 2030.
- The National Research Council report, *America's Energy Future,* in 2009 estimated potential cost-effective energy savings in the U.S. of about 20% in 2020 and about 30% in 2030, with the greatest potential in the buildings sector (National Research Council, Limiting the Magnitude of Future Climate Change, 2010).
- The American Physical Society report, Energy Future: Think Efficiency (2008) estimated 572 TWh of electricity savings in the residential sector in 2030, and about 30% savings for the building sector as a whole, all below the retail price of electricity energy.
- The U.S. Department of Energy's Appliance Standards Programs has conducted extensive studies for regulated product types (http://www1.eere.energy.gov/buildings/appliance_standards/), identifying economically justified and technologically feasible energy efficiency improvements.
- The Energy Information Administration annually publishes additional efficiency scenarios, e.g., high technology cases, in conjunction with the Annual Energy Outlook (http://www.eia.doe.gov/oiaf/aeo/).

2.2. Construction of the Energy Demand Scenarios

Any study that aims to project energy efficiency improvements from specific technologies must make the link between unit-level improvements and national impacts. The current study achieves this using LBNL's Bottom-Up Energy Analysis System (BUENAS). As the name suggests, BUENAS is a bottom-up technology-oriented model, rather than a top-down macroeconomic model[7]. BUENAS combines unit-level efficiency scenarios with a forecast of stock size and turnover to calculate national energy savings impacts through 2030. Unit level energy demand by baseline and "target" technologies are collected in a database that the model takes as inputs, and which define the base case and high efficiency scenarios. Growth of the stock (number of units operating) by 2030 is a function of economic and population growth.

BUENAS uses minimum ~~efficiency~~ energy performance standards (MEPS) as a default policy, that is, it models a discrete change in the efficiency of equipment after a specific year. For the current study, we chose an implementation year of 2015, assuming that several years lead time are necessary between identification of efficiency targets, and making them mandatory.

[7] BUENAS is described completely in McNeil, M.A., V.E. Letschert and S.A.De la Rue du Can (2008). *Global Potential of Energy Efficiency Standards and Labeling Programs*. LBNL 760E.

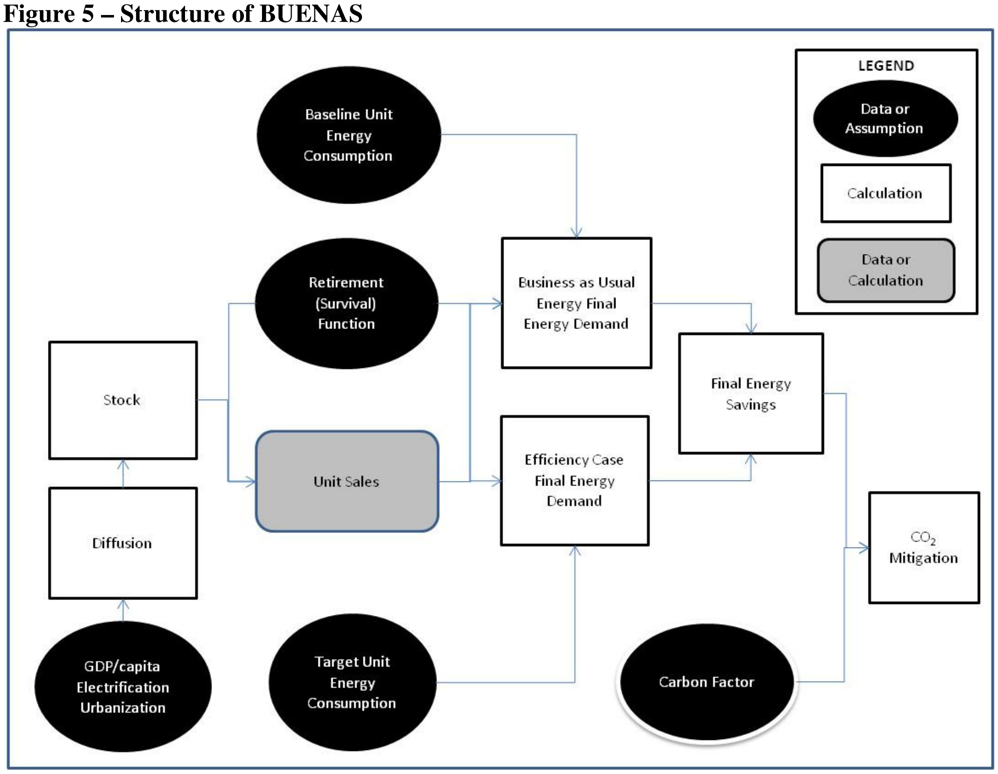
Originally constructed as a global model, BUENAS covers a wide range of energy-consuming products, including most appliance groups generally covered by Energy Efficiency Standards and Labeling programs around the world. The global model covered the following appliance groups:

- *Residential Sector:* Lighting, Refrigerators, Air Conditioners, Fans, Washing Machines, Standby Power, Televisions, Electric Ovens, Space Heating and Water Heating.
- *Commercial Building Sector:* Lighting, Air Conditioning, Refrigeration, Ventilation, Office Products, Space Heating and Water Heating.
- *Industrial Sector:* Electric Motors.

The BUENAS model uses the Long Range Energy Alternatives Planning (LEAP) platform[8] to forecast energy consumption by end use from 2005 (base year) to 2030. The strategy of the model is to first forecast end use *activity*, which is driven by increased ownership of household appliances and growth in the industrial sector. The total stock of appliances can be modeled either according to an econometric diffusion model or according to unit sales forecasts, if available. Electricity consumption or *intensity* of the appliance stock is then calculated according to estimates of the baseline intensity of the prevailing technology in the local market. Finally, the total final energy consumption of the stock is calculated by modeling the flow of products into the stock and the marginal intensity of purchased units, either as additions or as replacements of old units. The high efficiency or "policy" scenario is created by the assumption of increased unit efficiency relative to the baseline starting in a certain year. For example, if the average baseline unit energy consumption (UEC) of new refrigerators is 450 kWh per year, but a MEPS taking effect in 2012 requires a maximum UEC of 350 kWh per year, the stock energy in the policy scenario will gradually become lower than that of the base case scenario due to increasing penetration of high-efficiency units under the standard. By 2030, the entire stock will generally be impacted by the standard[9]. Figure 5 shows the analytical structure of -BUENAS.

[8] More information about the LEAP platform may be found at http://www.energycommunity.org
[9] This depends somewhat on the lifetime of the product. For refrigerators we may assume a 15 -year lifetime, but some refrigerators may last 20 years, so the turnover of the stock may not be complete by 2030.

Figure 5 – Structure of BUENAS



The main outputs of BUENAS are base case energy consumption forecasts to 2030 by end use and energy, energy saving impacts of the modeled policy, and carbon dioxide emissions mitigation impacts. For this study, financial impacts were added to the model in a spreadsheet calculation.

For the residential sector, *activity* is given by the stock of equipment, that is, the number of appliances installed and operating in Korean households in a given year.

Once the number of residential products in each appliance group in each year is established, this number is multiplied by the *UEC* to yield energy demand for the appliance group. *UEC* determines the efficiency scenario modeled. Determination of the baseline and efficiency scenario UEC is discussed below.

Finally, BUENAS tracks the introduction of each year's cohort of appliances into the stock, taking account of growth in the market, equipment retirements, and replacements. Retirement and survival functions are derived from average lifetimes and assumed to have a distribution around the mean value. This shape of the retirement function is assumed to be that of a normal distribution centered around the mean lifetime by default, but takes the form of a more complicated function (Weibull distribution) if such a distribution is available. The survival function is given by:

$$Survival(age) = 1 - \int Retirement(age)$$

Using the retirement distribution, the model calculates the weighted average efficiency of the stock in each year. In the case of the high efficiency scenario, only a small fraction of the stock operates at high efficiency in the years immediately following the policy start date, but this fraction grows over time. The percentage of stock operating in 2030 that was installed after the policy start date is dependent on the assumed average lifetime of the product class.

3. Efficiency Improvement Potential – Cost-Benefit Analysis

Cost-effectiveness is defined in terms of cost of conserved energy, that is, how much the end user must pay in terms of annualized incremental equipment investment for each unit of energy saved by higher efficiency equipment. The formula for cost of conserved energy is

$$\boldsymbol{CCE = \frac{I \times q}{S}} \qquad \text{Equation 1}$$

In this equation, *I* is the total additional investment needed to purchase high efficiency equipment rather than the baseline technology, and *S* is the resulting annual energy savings. The capital recovery factor *q* is given in turn by:

$$\boldsymbol{q = \frac{d}{(1 - (1 + d)^{-L})}} \qquad \text{Equation 2}$$

In this equation, *d* is the end user discount rate and *L* is the average lifetime of the equipment, in years. Defined in this way, *I* times *q* is an annual payment for an amortized capital investment. Cost of conserved energy is a convenient metric for comparison of cost-effectiveness of measures[10].

3.1. Cost of Conserved Energy Calculation

The Korean Energy Efficiency Label and Standard Program (EELSP) described in Table 1 has produced datasets of products and sales in the Korean market, published in (Choi, 2012a) and (Choi, 2012b). For each appliance group the datasets provide us technical descriptions, retail costs, efficiency levels, energy consumption, and 2010 sales of models sold on the Korean market. With these datasets we were able to evaluate cost of conserved energy as described in this section. More information on how the dataset is used is described in section 3.2.

As mentioned in the previous section, annual unit energy consumption (*UEC*) and equipment price (*Price*) are shown for all product classes considered in the analysis in the Appendix, unless

[10] Other metrics such as life cycle cost and payback period establish cost effectiveness, but are not easily compared across disparate technologies and appliance groups.

otherwise specified[11]. These parameters are used in the calculation of cost of conserved energy according to Equation 1 by comparing each design option to the baseline, according to:

$$I = Price_{DesignOption} - Price_{Baseline}$$

And

$$S = UEC_{Baseline} - UEC_{DesignOption}$$

The parameters used in calculation of q in Equation 2 are as follows:

Product Lifetime (*L*) – Average number of years that a product is used before failure and retirement. Lifetimes vary by product class and are estimated from manufacturer reports, or from survey data. This is a technical lifetime, and in some cases may not be the same as the length of time Koreans use the product before reselling or disposing of a useful product.

Discount Rates – In order to evaluate cost-effectiveness to consumers, the analysis takes into account the consumer discount rate. The rate represents estimated interest charges on any debt taken on to purchase the appliance. For Korea we assume rates similar to other developed countries modeled in BUENAS, with a residential discount rate of 5%, a commercial and industrial rate of 6%[12].

Energy Prices – The EELSP datasets (Choi, 2012a) and (Choi, 2012b) assume 0.145 USD per kWh, or about 160 Won per kWh, in calculating energy costs for all sectors. We adopt their assumption in this report, although we use commercial- and industrial-sector specific tariffs of 0.103 USD and 0.070 respectively. The natural gas tariff used from the Korea Energy Economics Institute is 708.9 Won/m^3 or 16.55 USD/GJ (KEEI, 2011). We assume that retail prices do not change, in real terms over the forecast period. Energy price assumptions are shown in Table 6. Prices are in 2010 USD, converted from the Korean Won (Finance, 2012)[13].

Table 6 – Energy Price Assumptions [119][NDB20]

Sector	Electricity Tariff		Source
	USD/kWh	Won/kWh	
Residential	0.145	160	(KEMCO, 2012b)
Commercial	0.103~~086~~	113~~99~~	(MKE, 2011~~KEEI, 2011~~)
Industry	0.070~~66~~	77	(KEEI, 2011)
	Natural Gas Tariff		
	USD/GJ	Won/kWh	
Residential	16.55	18,205	(KEEI, 2011)

[11] Additional products were evaluated for cost-effectiveness with the result that no cost-effective improvements were possible beyond the current standard. These results are not included in the Appendix.

[12] Our developed country discount rates match the values commonly used in US standards, e.g. *Refrigerator and Freezers Final Rule: Technical Support Document, USDOE, 2011.*

[13] 2010 and 2011 USD to Won ratio hovered between 1200:1 and 1100:1, but in 2011 it stayed close to 1100, so we used that as our conversion rate.

Unit Energy Consumption – The annual energy consumption, described in either kWh per year or GJ per year. EELSP data provided the sales of different efficiency levels, which allows for the calculation of market-weighted average UECs and equipment prices to yield a *market weighted baseline*. We first calculate the market shares using roll up scenarios. For example, the level 2 scenario in Table 7 is calculated with the baseline and level 1 market shares rolled up to level 2 and level 3 market shares are unaltered. This simulates a MEPS which brings all of the inefficient part of the market to the new standard. We then weight UEC and price based on these new shares. In the level 2 example the 'rolled-up' sales weighted UEC is 585 kWh per year, which expresses what the market average UEC will be with a level 2 MEPS. Finally, we calculate CCE for all the roll-up scenarios, and then evaluate the cost-effectiveness of those CCE values against the cost of energy.

Table 7 – Baseline Unit Energy Consumption Adjustment

Energy Efficiency Level	**UEC (kWh)**	**Market Shares**							
		Base Case	**Efficiency Level Roll-Up Scenarios**						
			1	**2**	**3**	**4**	**5**	**6**
Baseline	716	13%						
1	645	1%	12%					
2	609	19%	20%	**32%**				
3	573	67%	68%	68%	100%			
4	537	0%	0%	0%	0%	100%		
5	501	0%	0%	0%	0%	0%	100%	
6	457	0%	0%	0%	0%	0%	0%	100%
Sales Weighted UEC		597	589	**585**	573	537	501	457

In the case of residential freezers and split room air conditioners, we constructed hypothetical efficiency grades beyond grade 1. The grades are labeled A, B, C and onward. With freezers, each additional grade is 5% more efficient than the last efficiency grade, and with split room air conditioners each new efficiency grade is 15% higher than the last.

Prices- Prices were provided in the EELSP dataset. The UECs used for design options in this report correspond to the minimum requirements for different Korean efficiency grades. In order to provide an accurate price for these efficiency points, we take a regression analysis in order to determine how the price of an appliance is driven by capacity and efficiency. Since efficiency and capacity metrics vary between end uses, the specific parameters used are listed in the appendices. The price is assumed to increase as a power law according to capacity and UEC, so price increases more with larger and more efficient appliances. This is meant to imply that a manufacturer increases price as more material is required to make the product more efficient.

$$\frac{P}{P_0} = e^a \times \left(\frac{UEC}{UEC_0}\right)^b \times \left(\frac{Cap}{Cap_0}\right)^c \qquad \text{Equation 3}$$

Where P = Price; P_0 = Reference Price, UEC = Unit Energy Consumption; UEC_0 = Reference UEC; Cap = Capacity; Cap_0 = Reference Capacity. The reference variables are set just below the lowest known price, UEC, and capacity among the models in the EELSP dataset. In our analysis we use a power law with reference variables so we can observe the magnitude of change in price, UEC and capacity. The exponent b is expected to be negative, since it is less expensive to have a less efficient product. To calculate the relationship between price, UECs and capacity, we performed a multivariable regression. To do regression analysis, we first take the natural log of both sides of Equation 3:

$$\ln\left(\frac{P}{P_0}\right) = a + b \times \ln\left(\frac{UEC}{UEC_0}\right) + c \times \ln\left(\frac{Cap}{Cap_0}\right) \qquad \text{Equation 4}$$

Then we set term *ln(P)* as the dependent variable, *ln(UEC)* and *ln(Cap)* as the independent variables and ran the regression. The linear regression determines the value of parameters *a, b* and *c*. When the regression results show correlation between price, UEC and capacity, we plug the values of *a, b* and *c* back to Equation 3 and compute the price value according to the already determined UEC levels and average capacities. LCD televisions, three phase motors and commercial refrigerators are exceptions to this methodology, and the data and approach to those appliance groups are described under section 3.2.

Using these parameters, we calculate cost of conserved energy for each design option for each product class. The results of this calculation, shown in the Appendix tables, are the basis of construction of the efficiency scenario.

As stated above, the target efficiency level chosen is that which *maximizes efficiency while providing a net benefit to consumers*. Following this definition, we identify the target UEC for each product class as the lowest UEC for which cost of conserved energy is below the utility price.

Split Room Air Conditioner Example

Split Room Air Conditioner Product Classes – EELSP divides split room air conditioners into rated cooling capacity ranges of everything below 4 kW, 4 kW up to 10 kW, 10 kW up to 17.5 kW, and 17.5 kW up to 23 kW. According to 2010 sales, these product class ranges have average capacities of 2375 W, 5905 W, 12,320 W, and 19261 W, respectively These categories are divided according to the Korean MEPS rated cooling capacity range, as seen in Table 8 (MKE 2011).

Table 8 - Korean Air Conditioner Minimum Energy Performance Standard[121]

Type		MEPS (EER) Effective date: From 1st January, 2010~~04~~[NDB22]
Split Type	RCC < 4.0kW	3.37
	4.0kW ≤ RCC <10.0 kW	2.97
	10.0kW ≤ RCC < 17.5kW	2.76
	17.5kW ≤ RCC < 23.0kW	2.63

RCC: Rated Cooling Capacity

Window air conditioners are not common in Korea, and the dataset only showed 5 models on the market in 2009 and 2010, and in 2010 window air conditioners were only 0.1% of total shipments, so no analysis was done on that product. Amongst the split room air conditioner product classes we evaluate 11 possible design options, the first 5 being levels 5 through 1 of the Korean energy efficiency grade label (KEMCO, 2012a). The rest are hypothetical design options more efficient than efficiency label 1, each successively 15% more efficient than the last. Room air conditioners have a 12 year lifetime (Shah et al., 2012)[14]. Prices are in 2010 USD, converted from the Korean Won (Finance, 2012)[15].

Split Room Air Conditioner Unit Energy Consumption- Unit Energy Consumption (UEC) for Levels 5 to 2 are calculated according to Equation 1. Across the 4 product classes in Korean split type ACs, Level 1 has the same EER as Level 2, but has a lower UEC because it has a standby efficiency of 1 watt or less during off mode. We estimated that this causes a 3% reduction in UEC[16]. UEC for hypothetical Levels A through F are each 15% more efficient than the previous level, with level A being 15% more efficient than Level 1.

$$\boldsymbol{UEC} = \frac{\boldsymbol{Capacity\ (kW)}}{\boldsymbol{EER}\left(\frac{\boldsymbol{W}}{\boldsymbol{W}}\right)} \times \boldsymbol{Annual\ Use}\left(\frac{\boldsymbol{Hours}}{\boldsymbol{Year}}\right) \times \boldsymbol{Running\ Rate}\ (\%) \qquad \text{Equation 5}$$

The capacity of each product class was determined base on the average capacity weighted by shipments. Within each product group, energy level is corresponded to the different EER numbers shown in Table 10. We assume that all product classes are assumed to operate 732 hours in a year and that they run at full capacity during 60% of those hours (Choi, 2012a).

Split Room Air Conditioner Price - To compute price, we regress capacity and UEC against price, as shown in Equation 4. Taking the 4 to 10 kW category as an example, Table 9 shows our

[14] For the rest of the document, appliance lifetimes will only be shown in the appendix, not in-text.
[15] 2010 and 2011 USD to Won ratio hovered between 1200:1 and 1100:1, but in 2011 it stayed close to 1100, so we used that as our conversion rate.
[16] Korean standards also designate a 3 watt ceiling for active standby mode for room air conditioners with a network function, but we have no data for that technology type.

regression results and Table 10 shows the values needed to complete the regression and the UEC determination:

Table 9 – Price Regression Results for Split Room Air Conditioners

Product Class	R^2	N	Capacity			Efficiency		
			Variable	Regression Coefficient	P-Value	Variable	Regression Coefficient	P-Value
Split Room Air Conditioner	0.6	400	Rated Cooling Capacity	1.52	3.41 E-56	UEC	-0.82	8.73E-23

Table 10 - Split Room Air Conditioner Price Regression Assumptions

Group	Capacity	EER*	Annual Use	Running Rate	Reference
RCC < 4.0kW	2375W	3.37	732 hours[123][NDB24]	60%	(Choi, 2012a)
4.0kW ≤ RCC <7.5kW	5905W	2.97			
10.0kW ≤ RCC < 17.5kW	12320W	2.76			
17.5kW ≤ RCC < 23.0kW	19261W	2.63			

*UEC from level 2 to level 1 has a 3% increase; all EER levels are baseline number.

Continuing to take the 4 to 10 kW category as an example, Table 11 shows the different design options being evaluated for cost effectiveness. As the most efficient level with a CCE below the consumer tariff of 0.145 USD per kWh, grade 3 is the business case target, for a 10% decrease in annual unit energy consumption**.**

Table 11 – Cost of Conserved Energy Calculation for Split Room Air Conditioners

Appliance Group	Split Room Air Conditioners						
Product Class	Split 4 kW - 10 kW						
Market Share	42%						
Lifetime	12						
Capital Recovery Factor - Q	0.1128						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	873	943	35.0%	35.0%	693	1172	
Grade 4	765	1051	1.2%	36.2%	655	1210	0.113
Grade 3	**672**	**1169**	**13.5%**	**49.8%**	**622**	**1252**	**0.127**
Grade 2	589	1302	0.2%	50.0%	581	1318	0.147
Grade 1	572	1335	50.0%	100%	572	1335	0.152
A	486	1526	0%	100%	486	1526	0.193
B	413	1743	0%	100%	413	1743	0.230
C	351	1992	0%	100%	351	1992	0.271
D	298	2277	0%	100%	298	2277	0.316
E	254	2602	0%	100%	254	2602	0.367
F	216	2974	0%	100%	216	2974	0.426
In-Class Target UEC	622						
End-Use Baseline UEC	495						
End-Use Target UEC	450						
End-Use Target CCE	0.129						

3.2. Equipment Data

The evaluation of cost-effectiveness of Korean technologies relied heavily on efficiency and price data from the Energy Efficient Label and Standard Program (Choi, 2012a) and (Choi, 2012b). Identification of efficiency for most products studied was facilitated by the mandatory label program, covering 35~~2~~ product types, [125][NDB26]since most models were identified with a specific 1 to 5 efficiency grade, where the 5th grade is the minimum allowed efficiency and grade 1 is the most efficient level. Unit energy consumption for each level is calculated using the EELSP MEPS formulas (Choi, 2012a), with necessary assumptions such as average volume found in the data sets. Prices are also provided in the datasets, and we perform multiple variable regressions against of both efficiency metrics and capacity against price. The regressions, if statistically valid, provide the cost to efficiency relationship needed to determine prices for the efficiency grade UEC levels. Out of the 35~~2~~ products covered by the national efficiency program, 14 were provided as cost and efficiency datasets. Out of those datasets, 4 have enough information, a statistically significant efficiency to cost signal, and a cost effective target. Two of the other appliance groups, motors and LCD televisions, use different approaches to determine prices, described below. We also have cost effective results for commercial refrigerators, but the prices are sales averages, not the result of a price regression analysis. Lifetimes used represent the technical lifetime, which is the number of years the average product is useable before it requires replacement.

Residential Freezers

Residential freezers are a relatively small market with 96,000 sales in 2010, compared to 2 million sales of refrigerators. The baseline efficiency for freezers is 386 kWh per year with the efficiency case achieving 214 kWh per year cost effectively. The lifetime of domestic freezers is assumed to be 15 years. [127][NDB28]

Split Room Air Conditioners

Korea boasts a 20% improvement in room air conditioners from 1996 to 2010. The smallest split room air conditioners, with less than 4 kW cooling capacity, make up just over 50% of the market but had no cost effective option. The next 3 size groups, each with increasingly larger class cooling capacities, are cost effective at increasingly efficient targets. The 4 kW to 10 kW class makes up 42% of the market and is cost effective against the baseline up to efficiency grade 3. The 10 kW to 17.5 kW class is 1.2% of the market and the cost effective target is hypothetical grade A, which is 15% more efficient than the minimum qualification for grade 1. Finally, the 17.5 to 23.5 kW class is 0.2% of the market and has a cost effective target at grade C is 39% more efficient than the grade 1 cutoff. As a whole, split room air conditioners achieve a 0.5% EER improvement, from a baseline of about 3.30 EER and achieve a group target of about 3.31, while assuming a 12 year life span.[129][NDB30]

Motors

Motors in Korea comprise 60% of the national power consumption by single units of machinery (KEMCO, 2012c). Three phase motors are 40% of national power consumption. In 2008 Korea mandated IE2 standard motors, and now the national average motor efficiency lies between IE2 and IE3[17]. In 2012, Korea established a multi-year phase-in of IE3 motors, including financial subsidies and pilot projects with industry 'challenge programs'. All three phase motors are under the mandatory MEPS by 2017. This regulation, while already established, was chosen as a part of the Business Case instead of the baseline since the implementation date is beyond 2015. For this end-use, we are demonstrating its cost effectiveness and modeling the potential impacts of the success of an announced program. Korea is requiring large motors to meet the standard in 2015, medium capacity motors in 2016, and small motors in 2017. We are modeling all motors for IE3 in 2017, so our analysis is conservative in its measure.

Motors are not based on [131][NDB32]the price regression approach described in Section 3.1. The target is a coupling of the unit energy consumption of the IE3 standard with prices of NEMA-Premium rated motors from the U.S. The NEMA-Premium prices were gathered from the MotorMaster+ software (USDOE, 2010). The baseline UEC is derived from EELSP data and the price is calculated from interpolating Korea's point along price-efficiency curves between NEMA-Premium and EPACT standard motors. Results show that it is very cost effective to go from Korea's three phase motor average of 87.6% to 88.6%. We assume enclosed 4-pole 60 Hz motors as the representative class.

[17] Motor efficiency classes are defined by the standard IEC 60034 – see http://www.iec.ch/

Commercial Refrigerators

Figure 6 – A Typical Four Door Commercial Refrigerator under Korean Regulation

Commercial refrigerators have been regulated since 2010 and are analyzed as two types, refrigerator only systems and refrigerator-freezer systems. Units with freezers comprise 86% of the market, and refrigerator-only is 14%. Some standards programs, such as those in the United States or Australia, focus on refrigerated display units such as those found in grocery stores. The Korean standard and labeling program focuses on commercial refrigerators that one might find in a restaurant kitchen, non-display models with 300 to 2000 L of storage volume and with cooling power of less than 1 kW (Choi, 2012b). Smaller models have two doors vertically stacked, larger models have four doors in a square configuration, and several models have more doors. The average commercial refrigerator in 2010 consumed 1467 kWh per year. Both refrigerator and refrigerator-freezer classes are cost-effective at the second highest efficiency grade, a 32% improvement at 1001 kWh per year. Commercial refrigerators are assumed to have a 10 year lifetime. [133][NDB34]

Unlike the other products analyzed in this report, commercial refrigerator prices were not derived from a cost-efficiency relationship (see section 3.1). Improvements in commercial refrigerator efficiency are not currently reflected in the cost of the unit[18], so we have used the shipments-weighted average price of the models at the different efficiency grades. (Choi, 2012b) points out that energy efficient technologies have not been adopted for the recently regulated commercial refrigerators, unlike residential refrigerators which have been regulated for many years. The current standards should instigate future generations of the commercial refrigerator market to include more efficient designs, precipitating a determinable relationship between cost and efficiency.

Residential Refrigerators

Domestic refrigerators account for 21% of the household power consumption in Korea (KEMCO, 2012c). ~~Korean refrigerators have one of the lowest energy consumption levels, per liter, in the world (KEMCO, 2012c). [135]~~[NDB36]Korean standards distinguish 4 classes[19]. Two of those classes, refrigerator-only models and refrigerator-freezer models over 500 adjusted liters with an ice-dispenser or home-bar door, represent 7.5% of the 2010 market. But our statistical regression has shown that the price variation in these two classes cannot be explained by variation in energy efficiency. Higher efficiency among models in those two classes is not a predictor for increased retail cost, so we cannot evaluate these classes for cost-effective efficiency improvements. Even though we cannot produce targets for these classes, we still take them into account for our appliance group baseline. In order to do this, we calculate that the 7.5% of the residential refrigerator market that come from these two classes will not change, thus modeling future unit

[18] Since improvements are not reflected in the cost of the unit, it is possible to calculate a negative CCE, as is the case with the refrigerator-only class target.
[19] Kimchi refrigerators are regulated, but are a separate product category in Korean standards.

energy consumption for that part of the market at the current consumption levels. The other 92.5% of the refrigerator market is composed of refrigerator-freezer models below 500 adjusted liters and refrigerator-freezer models above 500 adjusted liters without an ice-dispenser or home-bar door. These two classes do show a price signal and form the basis of our cost-effectiveness evaluation.

Among refrigerator-freezer models below 500 adjusted liters, 95% of the market is at the two lowest efficiency grades, forming an average annual unit energy consumption of 436 kWh. The highest efficiency grade 1 is cost-effective for Korean consumers. This target, at 283 kWh, is 35% lower in annual energy consumption compared to the baseline. 2010 sales indicate that among the refrigerator-freezer models above 500 adjusted liters without an ice-dispenser or home-bar door 82% of the market is already at the first efficiency grade. Even though there is already a low average UEC baseline of 460 kWh per year, it is cost effective for the market to eliminate the three lowest efficiency grades. This means that 82% of the market is still held at grade 1, but the remaining 18% of the market can be cost-effectively 'rolled-up' to grade 4 from grade 5, which improves the class UEC to 441 kWh per year. While this is a modest improvement compared to the improvement potential of sub-500 liter models, the modest improvement yields substantial results since it applies to 58% of the entire refrigerator market. Across all classes, domestic Korean refrigerators can cost effectively improve from 430 kWh per year to 366 kWh per year. Residential refrigerators are assumed to have a 15 year lifetime.

[137][NDB38]*Gas Boilers*

In Korea residential gas boilers represent about 50% to 60% of city gas consumption (KEMCO, 2012c). Based on 2010 sales, almost 90% of the boiler market stands at grades 4 and 3 of the EELSP rating system. 10% of the market is composed of condensing boilers, a technology level required to garner Korea's 1st grade ranking. We find that it is cost effective for the entire market to shift to condensing boilers, which will yield a 5% savings in yearly energy consumption by shifting from a 30 GJ/year UEC to 28. This is a thermal efficiency change from the baseline average of 83% to the grade 1 requirement of 87%. Gas boilers are assumed to have a 17 year lifetime.

LCD Televisions

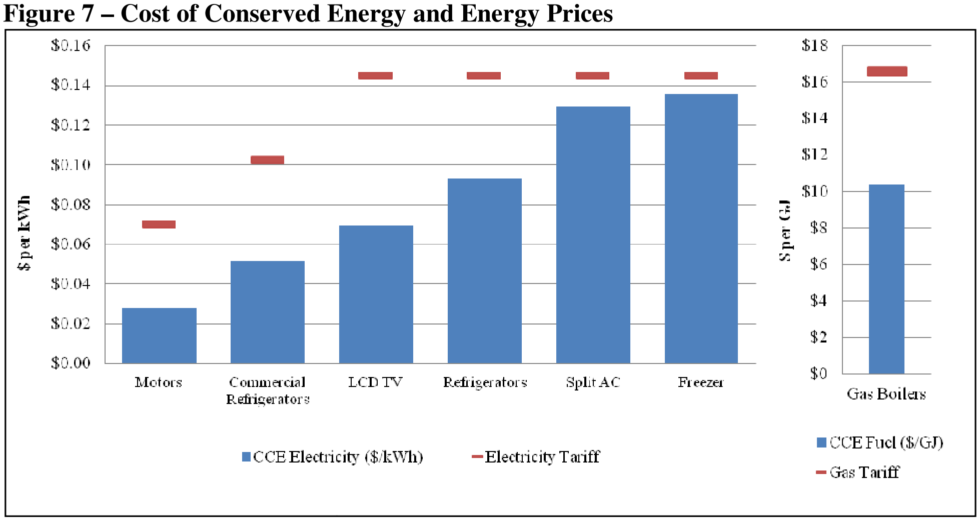
By 2015, 96% of the Korean LCD TV market is expected to consist of edge-lit LED-LCD televisions, with only 3% of the market still in CCFL LCD technology. OLED televisions are forecasted at 1% of the market(Park et al., 2011). Televisions in Korea are used for approximately 6 hours in a day and the baseline television has an Energy Efficiency Index (EEI) of 0.228. The cost effective target design includes improved optical films involving Dual Brightness Enhancement Film and also dimming technologies that not only reduce energy consumption but also improve image quality in terms of contrast-ratio. These improvements result in an EEI of 0.158. LCD televisions are assumed to have a 8 year lifetime[139][NDB40]. The baseline and cost effective targets are based on (Park et al., 2011).

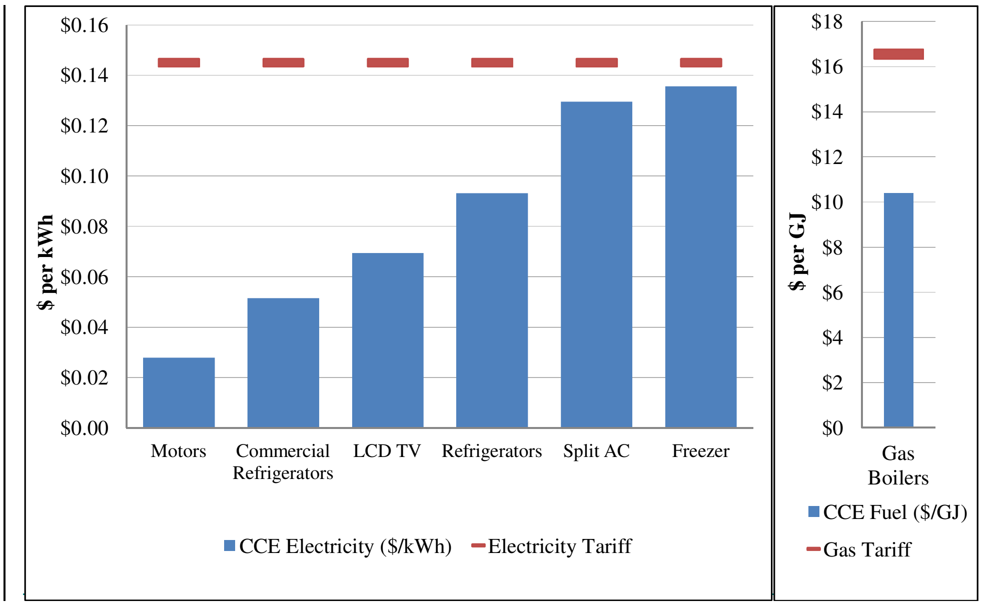
Other Appliance Groups

The EELSP dataset included 14 appliance groups, but limitations in data and cost effectiveness pared down the set to the 7 listed here. Distribution transformers, an appliance group which we have seen having considerable energy savings potential in other countries, only had enough data for identifying a baseline and no information concerning high-efficiency options. Residential water heaters in Korea are sometimes used instead of boilers in Korea, but no cost effective options are on the market. The least expensive design option for Korean water heaters is 22 USD per GJ saved in comparison to the baseline, so there is no cost effective target since the cost of a GJ of natural gas in Korea is 16.6 USD. In several cases the data did not provide a robust signal for price from energy efficiency, as is the case for washing machines. This could be due to other features which are not being accounted for in the regression, small data sets, or simply an appliance group lacking energy efficiency as a driver of different on-the-market designs. Finally, the case of lighting and standby is missing from this report because Korea already has transformed its market towards compact fluorescent lighting and reduced standby power consumption. In the case of standby, a recent study showed Korean products already go well below 1 W of off-mode power consumption (Kim, 2011).

The Appendix tables show the calculation of CCE for each product class, and calculate weighted average target UEC and CCE for each appliance group. The cost of conserved energy for all appliance groups is compared to utility prices in Figure 7.

Figure 7 – Cost of Conserved Energy and Energy Prices





The main inputs to the construction of the two scenarios, the *Base Case* and the *Business Case* scenario are the baseline UEC and the UEC established by CCE in Figure 2. We call this the *Business Case UEC*. Baseline UEC, *Business Case* UEC, Percent Improvement and Cost of Conserved Energy are presented in Table 12.

Table 12 – Unit Grade Efficiency Improvement and Cost of Conserved Energy

Appliance Group	Product Class	Baseline UEC	Target UEC	Target CCE	Percent Improvement
Electric Equipment		kWh		$/kWh	
Commercial Refrigerators	All	1467	1001	0.051	32%
	Refrigerator only	673	521	-0.039	23%
	Refrigerator-Freezer	1596	1078	0.056	32%
Residential Refrigerators	All	430	366	0.093	15%
	Refrigerator only	149	No CCE below Tariff		
	Refrigerator-freezer whose compensated cubic volume is less than 500 L	436	283	0.084	35%
	Refrigerator-freezer whose compensated cubic volume is no less than 500 L without ice-dispenser or homebar door	460	441	0.138	4%
	Refrigerator-freezer whose compensated cubic volume is no less than 500 L with ice-dispenser or homebar door	628	No CCE below Tariff		

Residential Freezers	Freezers	386	214	0.136	44%
Split Room Air Conditioners	All	495	450	0.129	9%
	Split RAC 4kW and under	309	No CCE below Tariff		
	Split RAC 4kW to 10kW	693	622	0.127	10%
	Split RAC 10kW to 17.5kW	1917	966	0.135	50%
	Split RAC 17.5kW to 23.5kW	3217	1226	0.133	62%
Motors	Small 3-Phase General Purpose 0.75-7.5 kW (1.1 kW)	1335	1317	0.029	1%
	Medium 3-Phase General Purpose 7.5-75 kW~~H~~ (11 kW)	19086	18928	0.030	1%
	Large 3-Phase General Purpose > 75 kW (110 kW)	391373	389397	0.021	1%
TV	LCD Television	40	39	0.069	1%
Fuel Products		GJ		$/GJ	
Gas Boilers	Gas Boilers	30	28	10.380	5%

Table 12 shows that energy efficiency improvements can be made to a wide variety of equipment that will provide not only energy savings, but financial benefits to consumers. It also demonstrates the importance of performing this type of analysis at the appliance group level, since the cost-effective potential varies widely between appliance groups.

4. National Level Energy Savings Opportunities

Because of the modular structure of the BUENAS model (see Figure 5), once the inputs are established it is a relatively straightforward process to construct the two energy demand scenarios and compare them to calculate savings potential. The full details of the calculation of energy demand are provided in (McNeil et al., 2012) and are omitted here.

4.1. Energy Savings and Emissions Reductions

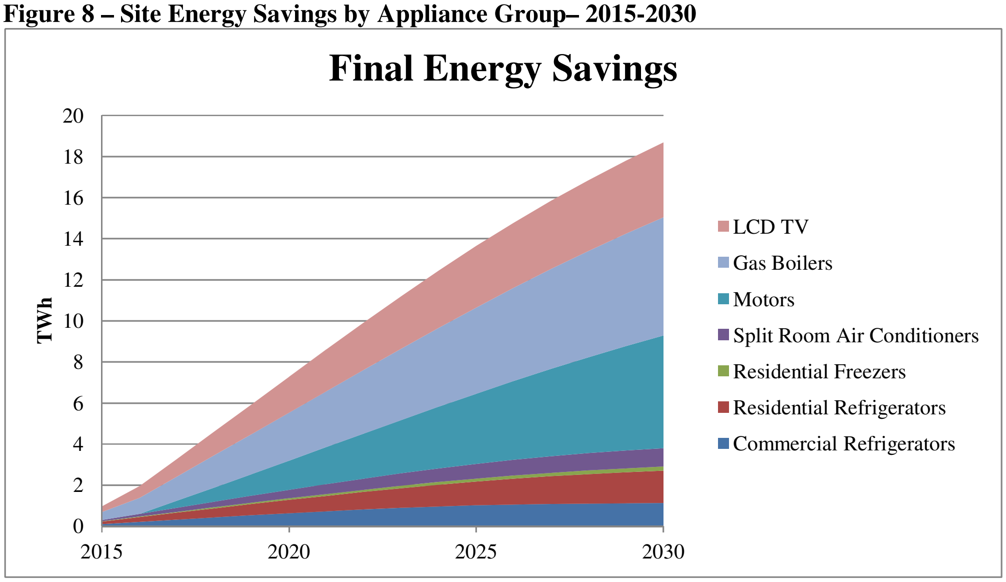
Site energy savings is the basis for all national impacts calculations. Site energy demand refers to electricity and natural gas consumed in a home or business, and does not include fuel inputs in generation of electricity, or losses in transmission or distribution. Site energy is the energy affected most immediately by efficiency improvement. It is also the energy consumption that appears on consumer utility bills, and forms the basis for the cost-benefit analysis detailed above.

Site energy consumption is calculated by BUENAS for both the *Base Case* and *Business Case* scenarios. Energy *activity* is the same in both cases[20], so the difference between them is driven by the trend in *marginal intensity*, that is, the UEC of products sold in each year. The UEC for

[20] It is possible to model, for example, the reduction of sales or fuel switching resulting from price increases associated with efficiency regulations. This effect is not captured in BUENAS.

the two scenarios are identical until the policy implementation date of 2015[21]. After that date, the efficiency target in the *Business Case* is the high efficiency level determined by cost-benefit analysis, while it remains at the baseline efficiency level in the *Base Case*. The difference in UEC in the two scenarios applies only to new products – in this way, the policy modeled has the structure of a minimum ~~efficiency~~ energy performance standard, and does not imply retrofits of existing equipment. By 2016 overall energy demand of stock in the *Business Case* is only slightly lower than the *Base Case*, because only one year's sales are affected by the policy. Moving through the forecast, LEAP tracks the gradual flow of high efficiency products into the stock and the retirement of less efficient ones, so that the average stock UEC gets closer to the target level. Depending on the lifetime of the product, the entire stock may not be converted by 2030, since some low-efficiency products installed before 2015 will survive. Figure 8 shows the evolution of site energy savings by appliance group. From 2015 onward, energy savings grows for all products as high efficiency products begin to penetrate the stock in the *Business Case*.

Figure 8 – Site Energy Savings by Appliance Group– 2015-2030



Site energy savings results are summarized in Table 13. Total savings for all appliance groups totals 14 TWh in the year 2030. Cumulative savings through 2030 total 130 TWh.

Emissions reductions are calculated directly from energy savings according to a carbon factor. The carbon factor for electricity includes fuel inputs to generation, and accounts for transmission and distributions losses. The carbon factor taken from (McNeil et al., 2012) is 0.436 kg CO_2/kWh in 2015, decreasing to 0.391 kg CO_2/kWh in 2030. The carbon factor for natural gas is assumed to remain constant at 0.202. Emissions reductions from energy savings determined by multiplying energy savings by carbon factors are shown in Table 13. Total mitigation in the

[21] The exception is the phase-out of incandescent lamps, which begins in 2012 in the *Business Case*.

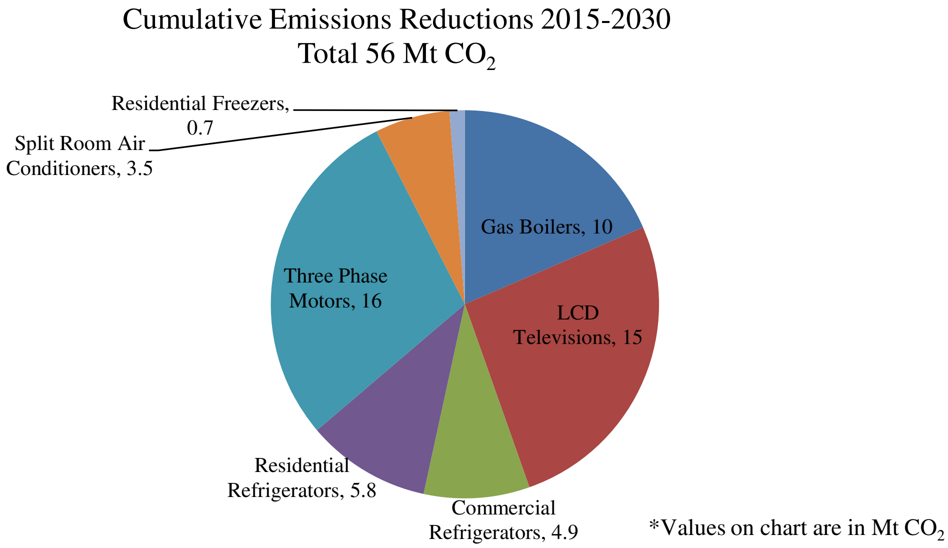
Business Case is found to be 4.5 Mt CO_2 in 2030 and 43 Mt CO_2 over the entire forecast. Figure 9 shows the contribution to cumulative CO_2 mitigation from all appliance groups.

Table 13 – Energy Savings and Pollutant CO_2 Mitigation by Appliance Group

	Final Energy Savings			Emissions Mitigation		
	In 2020	In 2030	Through 2030	In 2020	In 2030	Through 2030
Appliance Group	TWh			Mt CO_2		
Gas Boilers	2.3	5.7	51	0.47	1.2	10
Three Phase Motors	1.4	5.5	40	0.6	2.1	16
LCD Televisions	1.7	3.7	36	0.73	1.4	15
Commercial Refrigerators	0.63	1.1	12	0.27	0.44	4.9
Residential Refrigerators	0.65	1.6	14	0.27	0.62	5.8
Split Room Air Conditioners	0.41	0.90	8.6	0.17	0.35	3.5
Residential Freezers	0.079	0.19	1.7	0.033	0.076	0.71
Total	**7.3**	**19**	**160**	**2.6**	**6.2**	**56**

Several conclusions can be drawn from Table 13 and Figure 9. First, emission reduction potential is mostly composed of savings from the residential sector. Only motors and refrigerators were available for the commercial and industrial sector, respectively, which is reflective of the limited data. The largest potential exists for three phase motors, LCD televisions and gas boilers, which could provide about 127 TWh of electricity demand reduction and 41 Mt of CO_2 over the forecast period. Motors savings comes from adopting IE3 level motors by 2017. The Korean government has set this efficiency level as a national target, and it is a goal which we have found to be cost-effectively achievable. Savings in LCD televisions is possible due to dimming enhancements and improved optical films used in the screen. Gas boiler savings come from wide-spread adoption of condensing gas boilers. Korea boasts one of the world's most efficient residential refrigerator markets, even at 21% of household power consumption (KEMCO, 2012c) refrigerators still offer substantial energy savings at the marginal improvements we identified as cost effective. Commercial refrigerators have been labeled since 2010, and the highest efficiency grade is cost effective for both refrigerator and refrigerator-freezers. Combined, refrigerators offer about 26 TWh of energy savings for Korea. The remaining savings comes from improvements in split room air conditioners over 4kW in cooling capacity and a 44% increase in residential freezer efficiency.

Figure 9 – Cumulative CO2 Emissions Reductions 2015-2030



4.2. Consumer Financial Impacts

By construction, the *Business Case* implements energy efficiency in a way that is cost-effective to consumers. Because this study insisted on quantifying investments needed to improve efficiency relative to the base case technology, the necessary information to evaluate these investments and financial benefits of energy savings, and therefore net financial impacts to consumers, is available for all appliance groups considered. It is important to consider that the *Business Case* is not intended to achieve financial benefits, but to maximize energy savings. Since the cost of conserved energy is always kept below the price of electricity the difference between the two provides financial benefits.

First, the incremental cost of the *Business Case* scenario comes from the equipment purchases needed to replace existing stock with the target high-efficiency design. The total cost for a country in a given year is calculated as the *National Equipment Cost*:

$$NEC_{BAU}(y) = Price_{Baseline} \times Sales(y)$$

In the business-as-usual case (BAU), we multiply the national equipment sales by the baseline price which was introduced in section 3.1. For the *Business Case*, we replace the baseline price with the target design option:

$$NEC_{Business\ Case}(y) = Price_{Target} \times Sales(y)$$

The incremental cost of the *Business Case* scenario for a given year is calculated as the difference in national equipment cost between the two scenarios:

$$\Delta NEC(y) = NEC_{Business\ Case}(y) - NEC_{BAU}(y)$$

Secondly, the savings from the *Business Case* comes from the reduction in operating costs. The form for calculating the baseline case and the cost-effective case is similar:

$$NOC_{BAU}(y) = E_{BAU}(y) \times P(y)$$

$$NOC_{Business\ Case}(y) = E_{Business\ Case}(y) \times P(y)$$

Where *P(y)* is the cost of energy, as either the electricity tariff or cost of fuel. E_{BAU} and $E_{Business\ Case}$ are the total energy consumption values for the base case and the cost-effective case, respectively. These two equations combined provide the net national operating cost, forming the basis of savings for the *Business Case*:

$$\Delta NOC(y) = NOC_{Business\ Case}(y) - NOC_{BAU}(y)$$

The net financial impact N_T is the sum of net national operating cost and net national equipment cost:

$$N_T(y) = \Delta NOC(y) + \Delta NEC(y)$$

We begin all of our financial calculations in 2010, though the *Business Case* policy takes effect in 2015 (or 2017 in the case of motors). We assume the sales for the target technology end in 2030, though the benefits of installing the new technology are captured out to 2050. In evaluating the financial value of efficiency or other government programs, it is customary to take account of deferred benefits through a discount rate calculation. The resulting *Net Present Value* (NPV) of benefits is given by:

$$NPV = \sum_{y=2010}^{2030} \frac{N_T}{(1 + DR)^{y-2010}}$$

In this equation, *DR* is a "societal" discount rate that parameterizes the preference for immediate returns on public investments. In the BUENAS model, we assume a societal discount rate of 3% for Korea. Cumulative discounted incremental equipment costs, energy bill savings, net savings and *NPV* are shown in Table 14. The table shows positive net savings for all appliance groups, which is not surprising, since the target efficiency levels were constructed to be cost-effective. The table shows that cost-effective efficiency improvements require an investment of 8.2 billion USD over the next 20 years, but these investments will provide a return of over 200 percent over the same period through reduced operating costs. This results in a discounted net savings of 8.5 billion dollars, assuming a discount rate of 3-percent. The net savings is of order of two hundred dollars per capita. Of the appliance groups studied, gas boilers require the largest investment at 3.3 billion USD, but its payoff of 5.4 billion USD is two thirds more than the investment.

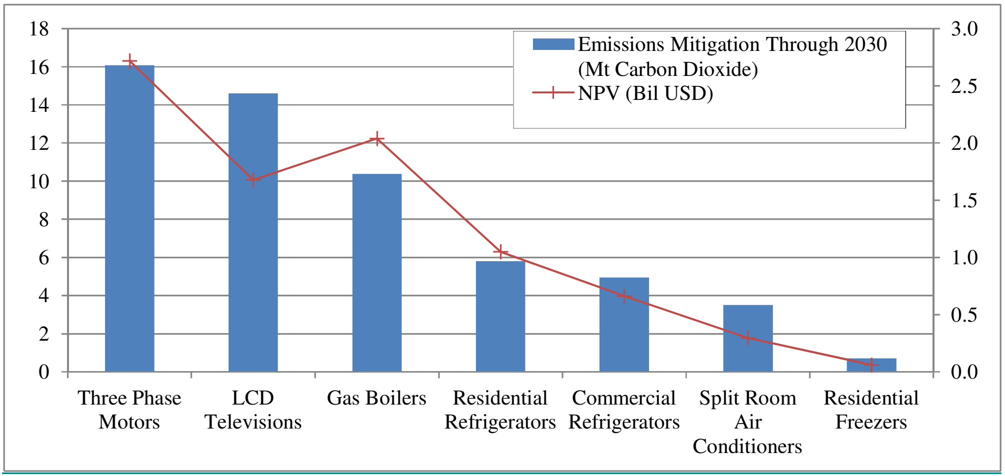
~~but these investments will provide a return of nearly 215-percent over the same period. This results in a discounted net savings of 9.3 billion dollars, assuming a discount rate of 3-percent. The net savings is of order of two hundred dollars per capita. Of the appliance groups studied, gas boilers require the largest investment at 3.3 billion USD, but have the highest payoff at 5.4 billion USD.~~

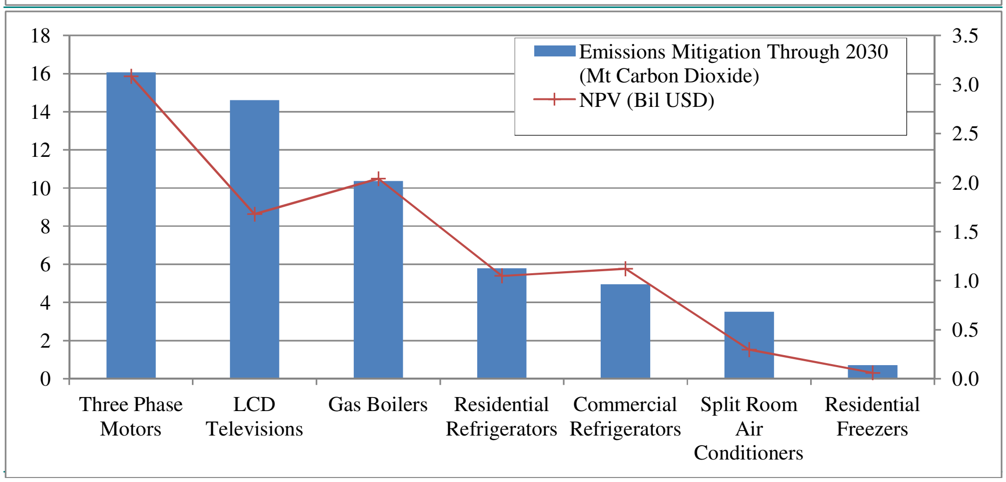
Table 14 – Cumulative Financial Impacts of Efficiency Improvement

Appliance Group	Cumulative Financial Impacts (Discounted @ 3% DR)		
	Equipment Cost	Operating Cost	NPV
	Billions USD		
Three Phase Motors	**0.94**	-34.7~~0~~	**2~~3~~.7~~1~~**
Gas Boilers	**3.3**	-5.4	**2.0**
LCD Televisions	**1.1**	-2.8	**1.7**
Commercial Refrigerators	**0.46**	-1.1~~6~~	**0.66~~1.1~~**
Residential Refrigerators	**1.2**	-2.3	**1.0**
Split Room Air Conditioners	**0.93**	-1.2	**0.30**
Residential Freezers	**0.22**	-0.28	**0.060**
Total	**8.2**	**-17~~8~~**	**8.5~~9.3~~**

In order to easily compare different appliance groups' emissions mitigation and present value benefit, Figure 10 overlays the two parameters. Motors have both the highest level of emission mitigation and net value, indicating high returns in both financial and environmental terms. LCD televisions offer a similar level of emissions mitigation. But compared to motors, the NPV is significantly lower, because LCD TVs have a similar level of financial ~~savings~~ cost combined with a ~~cost~~ savings of 2.8~~5~~ billion USD. ~~This is over three times the total cost of the investment of motors.~~ NPV for both commercial and residential refrigerators is roughly 1 billion USD. Split room air conditioners and residential freezers provide the least financial return on investment, though air conditioners can provide more carbon dioxide abatement than freezers.

Figure 10 - Financial Impacts for All Appliance Groups 2015-2030





Finally, we note that there are other benefits to the energy savings achieved in the *Business Case* besides the direct energy and financial benefits. The effect of reduction of greenhouse gas emissions and resulting avoided costs are difficult to quantify, but could be very large. One metric to consider the order of magnitude of the value of these types of impacts is the assumption of a carbon price. The assumption of a price of 25 USD per ton of carbon dioxide yields an additional 1.4 billion USD of savings, while a 100 USD per ton price yields 5.6 billion additional USD, increasing the total savings by over fifty percent.

5. Conclusions

The *Business Case* analysis found additional potential for cost-effective efficiency improvement in Korea for six appliance groups in the residential and commercial building sectors and industrial motors. Efficiency improvement for these technologies could deliver over 20~~2~~0% as much financial benefit to Korean households and business than the investment needed to implement them. In addition to direct financial benefits, impacts on greenhouse gas emissions and are significant. Total net impacts from additional deployment of high efficiency technology include:

Energy savings:

- 7.3 billion kWh per year in 2020
- 19 billion kWh per year in 2030
- A total of billion 160 kWh cumulatively through 2030

Cumulative greenhouse gas emissions mitigation:

- 56 million metric tons of CO_2 through 2030

Financial impacts to consumers through 2030:

- Equipment investment of 8.2 billion USD
- Energy bill savings of 17~~8~~ billion USD
- Net savings of 8.5~~9.3~~ billion USD

The "business case" analysis shows that the Korean market already has access to efficiency technologies that could provide Korean consumers with a financial benefit and make a dent in the growth of Korean emissions if widely adopted. Most of the equipment studied has been the subject of at least one efficiency standard, but opportunities for improvement are not exhausted. To some extent, therefore, the savings potential estimated by this study can be captured through expansion and aggressive pursuit of existing Korean government policies. It should also be noted that many of the technologies included in the "business case" scenario were not available ten to twenty years ago, or at least weren't be shown to be cost effective. These technologies have become available and cost-effective through research, new materials and components, improvements in production processes, or changes in design of systems. Likewise, we expect that a similar analysis performed 10 years from now will show improvements not accessible to the current study due either to lack of data or prohibitively high cost of "prototype" technologies.

Because the rigor of the methodology used to evaluate cost-effectiveness requires a significant amount of technical data, we only cover a subset of equipment types for which significant savings potential might be available. In particular, the appliance groups covered are limited to buildings applications. For this sector, however, we believe a large fraction of energy demand is accounted for. For this reason, while the overall savings potential is large, it cannot be interpreted as "comprehensive".

Finally, we believe this study to be among the few to attempt to evaluate the "economic" potential of efficiency improvement in Korea in a transparent way. In addition to demonstrating significant savings potential, we hope that it demonstrates a clear and consistent methodology for creation and expansion of alternative energy scenarios in Korea. Additional scenarios that could be explored include the potential impact of carbon taxes, cap-and-trade, R&D investments and other policy- or market-based drivers. The ability of the research community to utilize this type of analysis to inform government and private sector decision makers will depend largely on investments made in development of the type of data used here, both more widely and with greater frequency.

ACKNOWLEDGEMENTS

Useful information and comments were provided by Gi-Ho Yu, Young-Jae Jeon, Jeong-Hwan Kim, Su-Yeon Kim of Energy Efficiency Standardization & Certification Center in Korea Energy Management Corporation.

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APPENDIX – Efficiency-Cost Relationship and Cost of Conserved Energy Calculation for Appliance Groups

Parameters used in Calculation of Cost of Conserved Energy

Residential Consumer Discount Rate = 5%
Commercial Consumer Discount Rate = 6%
Industrial Consumer Discount Rate = 6%
Residential Electricity Price (2010) = $0.145 $/kWh
Commercial Electricity Price (2010) = $0.103~~145~~ $/kWh
Commercial Electricity Price (2010) = $0.070~~145~~ $/kWh
[NDB41]*Residential Natural Gas Price (2010)* $16.55 $/GJ

6. Cost of Conserved Energy Tables

***These tables are based on the EELSP dataset described in section 3.1 and 3.2 (Choi, 2012a and b).**

Table A. 6.1 – Cost of Conserved Energy Table for Split Room Air Conditioners under 4kW

Market Share	56.54%						
Lifetime	12						
Capital Recovery Factor - Q	0.1128						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	310	555	99.0%	99.0%	309	555	
Grade 4	284	595	1.0%	100.0%	284	595	0.18
Grade 3	261	639	0.0%	100.0%	261	639	0.19
Grade 2	239	686	0.0%	100.0%	239	686	0.21
Grade 1	232	703	0.0%	100.0%	232	703	0.22
A	197	804	0.0%	100.0%	197	804	0.25
B	168	919	0.0%	100.0%	168	919	0.29
C	143	1050	0.0%	100.0%	143	1050	0.33
D	121	1200	0.0%	100.0%	121	1200	0.39
E	103	1371	0.0%	100.0%	103	1371	0.45
F	88	1567	0.0%	100.0%	88	1567	0.51
In-Class Target Weighted UEC	No CCE below energy price						
In-Class Target Weighted Price							
In-Class Target Weighted CCE							

Table A. 6.2 – Cost of Conserved Energy Table for Split Room Air Conditioners 4kW-10kW

Market Share	42.12%						
Lifetime	12						
Capital Recovery Factor - Q	0.1128						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	873	943	35.0%	35.0%	693	1172	
Grade 4	765	1051	1.2%	36.2%	655	1210	0.11
Grade 3	**672**	**1169**	**13.5%**	**49.8%**	**622**	**1252**	**0.13**
Grade 2	589	1302	0.20%	50.0%	581	1318	0.15
Grade 1	572	1335	50.0%	100.0%	572	1335	0.15
A	486	1526	0.0%	100.0%	486	1526	0.19
B	413	1743	0.0%	100.0%	413	1743	0.23
C	351	1992	0.0%	100.0%	351	1992	0.27
D	298	2277	0.0%	100.0%	298	2277	0.32
E	254	2602	0.0%	100.0%	254	2602	0.37
F	216	2974	0.0%	100.0%	216	2974	0.43
In-Class Target Weighted UEC	622						
In-Class Target Weighted Price	1252						
In-Class Target Weighted CCE	0.13						

Table A. 6.3 – Cost of Conserved Energy Table for Split Room Air Conditioners 10kW-17.5kW

Market Share	1.19%						
Lifetime	12						
Capital Recovery Factor - Q	0.1128						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	1960	1480	86.0%	86.0%	1917	1512	
Grade 4	1650	1706	14.0%	100.0%	1650	1706	0.08
Grade 3	1391	1962	0.0%	100.0%	1391	1962	0.1
Grade 2	1171	2260	0.0%	100.0%	1171	2260	0.11
Grade 1	1136	2317	0.0%	100.0%	1136	2317	0.12
A	**966**	**2648**	**0.0%**	**100.0%**	**966**	**2648**	**0.14**
B	821	3026	0.0%	100.0%	821	3026	0.16
C	698	3458	0.0%	100.0%	698	3458	0.18
D	593	3952	0.0%	100.0%	593	3952	0.21
E	504	4517	0.0%	100.0%	504	4517	0.24
F	428	5162	0.0%	100.0%	428	5162	0.28
In-Class Target Weighted UEC	966						
In-Class Target Weighted Price	2648						
In-Class Target Weighted CCE	0.14						

Table A. 6.4 – Cost of Conserved Energy Table for Split Room Air Conditioners 17.5kW-23.5kW

Market Share	0.16%						
Lifetime	12						
Capital Recovery Factor - Q	0.1128						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	3217	1941	100.0%	100.0%	3217	1941	
Grade 4	2774	2192	0.0%	100.0%	2774	2192	0.06
Grade 3	2390	2477	0.0%	100.0%	2390	2477	0.07
Grade 2	2058	2801	0.0%	100.0%	2058	2801	0.08
Grade 1	1997	2872	0.0%	100.0%	1997	2872	0.09
A	1697	3282	0.0%	100.0%	1697	3282	0.10
B	1442	3750	0.0%	100.0%	1442	3750	0.12
C	**1226**	**4286**	**0.0%**	**100.0%**	**1226**	**4286**	**0.13**
D	1042	4898	0.0%	100.0%	1042	4898	0.15
E	886	5598	0.0%	100.0%	886	5598	0.18
F	753	6397	0.0%	100.0%	753	6397	0.20
In-Class Target Weighted UEC	1226						
In-Class Target Weighted Price	4286						
In-Class Target Weighted CCE	0.13						

Table A. 6.5 – Cost of Conserved Energy Table for Freezers

Market Share	100%						
Lifetime	15						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	536	495	27.4%	27.4%	386	636	
Grade 4	412	583	29.3%	56.6%	352	661	0.07
Grade 3	335	664	13.2%	69.8%	309	706	0.09
Grade 2	282	740	2.7%	72.5%	272	759	0.10
Grade 1	244	811	27.5%	100.0%	244	811	0.13
A	**214**	**878**	**0.0%**	**100.0%**	**214**	**878**	**0.14**
B	191	943	0.0%	100.0%	191	943	0.15
C	173	1005	0.0%	100.0%	173	1005	0.17
D	158	1065	0.0%	100.0%	158	1065	0.18
E	145	1122	0.0%	100.0%	145	1122	0.19
F	134	1179	0.0%	100.0%	134	1179	0.21
In-Class Target Weighted UEC	214						
In-Class Target Weighted Price	878						
In-Class Target Weighted CCE	0.136						

Table A. 6.6 – Cost of Conserved Energy Table for Gas Boilers

Market Share	100.0%						
Lifetime	18						
Capital Recovery Factor - Q	0.086						
Efficiency Grade	UEC (GJ)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	31	243	2.6%	2.6%	30	335	
Grade 4	30	286	30.1%	32.8%	30	337	6.51
Grade 3	30	336	57.1%	89.8%	30	353	7.7
Grade 2	29	414	0.5%	90.3%	29	423	9.14
Grade 1	**28**	**508**	**9.7%**	**100.0%**	**28**	**508**	**10.38**
In-Class Target Weighted UEC	28						
In-Class Target Weighted Price	508						
In-Class Target Weighted CCE	10.38						

Table A. 6.7 – Cost of Conserved Energy Table for Residential Refrigerator - Refrigerator only

Market Share	7.29%						
Lifetime	15						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	149	378	1.000	100.0%	149	378	
In-Class Target Weighted UEC	Not enough data point for regression; could not create cost curve						
In-Class Target Weighted Price							
In-Class Target Weighted CCE							

Table A. 6.8 – Cost of Conserved Energy Table for Refrigerator-Freezers- Adjusted Volume Less Than 500 L

Market Share	34.63%						
Lifetime	15						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	452	406	77.4%	77.4%	436	416	
Grade 4	393	444	17.9%	95.3%	391	446	0.06
Grade 3	348	481	4.3%	99.6%	347	481	0.07
Grade 2	312	517	0.0%	99.6%	312	517	0.08
Grade 1	**283**	**551**	**0.4%**	**100.0%**	**283**	**551**	**0.08**
In-Class Target Weighted UEC	283						
In-Class Target Weighted Price	551						
In-Class Target Weighted CCE	0.08						

Table A. 6.9 – Cost of Conserved Energy Table for Refrigerator-Freezers- Adjusted Volume Above 500 L without Ice-dispenser or Home-Bar Door

Market Share	57.86%						
Lifetime	15						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	826	877	0.8%	0.8%	460	1292	
Grade 4	570	1116	15.6%	16.4%	458	1294	0.090
Grade 3	516	1190	1.4%	17.8%	449	1306	0.125
Grade 2	**472**	**1262**	**0.1%**	**17.9%**	**441**	**1319**	**0.138**
Grade 1	435	1331	82.1%	100.0%	435	1331	0.149
In-Class Target Weighted UEC	441						
In-Class Target Weighted Price	1319						
In-Class Target Weighted CCE	0.138						

Table A. 6.10 – Cost of Conserved Energy Table for Refrigerator-Freezers- Adjusted Volume Above 500 L with Ice-dispenser or Home-bar Door

Market Share	0.21%						
Lifetime	15						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	628	3470	100.0%	100.0%	628	3470	
In-Class Target Weighted UEC	No CCE below energy price						
In-Class Target Weighted Price							
In-Class Target Weighted CCE							

Table A. 6.11 – Cost of Conserved Energy Table for Commercial Refrigerators – Refrigerator Only

Market Share	13.91%						
Lifetime	10						
Capital Recovery Factor - Q	0.096						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	1967	1245	0.2%	0.2%	673	1605	
Grade 4	1093	1618	26.6%	26.8%	672	1606	0.06
Grade 3	756	1141	7.0%	33.9%	581	1478	-0.19
Grade 2	**7. 578**	**8. 1388**	**9. 13.9%**	**10. 47.8%**	**11. 521**	**12. 1561**	**13. -0.04**
Grade 1	**14.** 468	**15.** 1720	**16.** 52.2%	**17.** 100%	**18.** 468	**19.** 1720	**20.** 0.08
In-Class Target Weighted UEC	468						
In-Class Target Weighted Price	1720						
In-Class Target Weighted CCE	0.08						

Table A. 6.12 – Cost of Conserved Energy Table for Commercial Refrigerators–Freezers

Market Share	86.09%						
Lifetime	10						
Capital Recovery Factor - Q	0.14						
Efficiency Grade	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
Grade 5	3019	1964	0.3%	0.3%	1596	1655	
Grade 4	1887	1608	59.3%	59.5%	1593	1654	-0.04
Grade 3	1372	1345	11.3%	70.8%	1286	1498	-0.07
Grade 2	**21. 1078**	**22. 1867**	**23. 29.1%**	**24. 99.9%**	**25. 1078**	**26. 1868**	**27. 0.06**
Grade 1	**28.** 888	**29.** 2382	**30.** 0.1%	**31.** 100.0%	**32.** 888	**33.** 2382	**34.** 0.14
In-Class Target Weighted UEC	888						
In-Class Target Weighted Price	2382						
In-Class Target Weighted CCE	0.14						

Table A. 6.13 – Cost of Conserved Energy Table for LCD Televisions
***This data is based on (Park et al., 2011), not on the EELSP dataset.**

Market Share	100%						
Lifetime	8						
Capital Recovery Factor - Q	0.155						
Back-Light Type	UEC (kWh)	Price 2010	Market Share	Cumulative MS	Weighted UEC	Weighted Price	Weighted CCE
CCFL	108.3	247.1	3.4%	3.4%	56.2	294.2	
Efficient CCFL (Enhanced Film)	86.6	252.4	0.0%	3.4%	55.5	294.4	0.038
LED	54.6	293.0	95.8%	99.2%	54.3	295.8	0.132
Efficient LED 1 (Enhanced Film)	43.7	297.9	0.0%	99.2%	43.5	300.7	0.078
Efficient LED 2 (Enhanced Film and Dimming)	**35.0**	**302.8**	**0.0%**	**99.2%**	**34.9**	**305.5**	**0.082**
OLED	24.4	634.4	0.8%	100%	24.4	634.4	1.654
In-Class Target Weighted UEC	34.9						
In-Class Target Weighted Price	305.5						
In-Class Target Weighted CCE	0.082						

Table A. 6.14 – Cost of Conserved Energy Table for Three Phase Motors - 60 Hz 4 Pole Enclosed Motor
***Table is based on Motor Master Plus data in addition to EELSP data.**

Size Category	Rated Output Power	Baseline UEC	Baseline Price	Target UEC	Target Price	CCE
Small	1.1	1335	124	1317	128	0.028
Medium	11	19086	1243	18928	1285	0.033
Large	110	391373	12417	389397	12850	0.028

Price Calculation Formula

$$P = e^{a} \times (UEC)^{b} \times (Capacity)^{c} \qquad \textbf{Equation A. 1}$$

*UEC interchangeable with EEI, depending on which is available from dataset

35. Regression Results

Table A. 35.1 – Table of Price-Regression Results for Split Room Air Conditioners

36. Product Class	37.	38. Number 39. of Observations	40. Capacity			41. Efficiency		
			Variable	Regression coefficient	P-Value	Variable	Regression Coefficient	P-Value
Split Room Air Conditioner	0.6	400	Rated Cooling Capacity	1.52	3.41 E-56	UEC	-0.82	8.73E-23

Table A. 35.2 – Table of Price-Regression Results for Freezers

42. Product Class	43. R^2	44. Number 45. of Observations	46. Capacity			47. Efficiency		
			Variable	Regression coefficient	P-Value	Variable	Regression Coefficient	P-Value
Freezer	0.49	15	Volume (L)	2.5	0.0066	EEI	0.6	0.45

Table A. 35.3 – Table of Price-Regression Results for Gas Boilers

48. Product Class	49. R^2	50. Number 51. of Observations	52. Capacity			53. Efficiency		
			Variable	Regression coefficient	P-Value	Variable	Regression Coefficient	P-Value
Gas boiler	0.59	132	Gas and Water heating (kW)	0.35	3.75E-06	EEI	5.79	3.86E-20

Table A. 35.4 – Table of Price-Regression Results for Residential Refrigerators

54. Product Class	55. R^2	56. Number 57. of Observations	58. Capacity			59. Efficiency		
			Variable	Regression coefficient	P-Value	Variable	Regression Coefficient	P-Value
Residential Refrigerator	0.49	425	Volume (L)	0.65	2.45E-21	EEI	0.65	1.38E-07

60. Minimum Energy Performance Standard (MEPS) Tables[142][NDB43]

Table A. 60.1 – Korean Air Conditioner Minimum Energy Performance Standard

61. Type		62. MEPS (EER) Effective Date: From January 1st 20~~04~~[144][NDB45]<u>**10**</u>
Window and Unitary room air conditioner		2.88
Split Type	RCC* < 4.0kW	3.37
	4.0kW ≤ RCC <7.5kW	2.97
	10.0kW ≤ RCC < 17.5kW	2.76
	17.5kW ≤ RCC < 23.0kW	2.63
*RCC: Rated Cooling Capacity		

Table A. 60.2 Freezers Minimum Energy Performance Standard

63. Type	64. MEPS
65. Freezers	66. P ≤ 0.028AV+32.40

Table A. 60.3 –Boilers Minimum Energy Performance Standard

67. Type	68. MEPS
69. Household Gas Boiler	70. 80.0 %

Table A. 60.4 –Residential Refrigerators Minimum Energy Performance Standard

71. Product class	72. MEPS From 1st of January 201~~1~~[146][NDB47]<u>**2**</u>
Refrigerator only	P ≤ 0.037AV+16.75
Refrigerator-freezer whose compensated cubic volume is less than 500 L	P ≤ 0.025AV+29.45
Refrigerator-freezer whose compensated cubic volume is no less than 500 L without ice-dispenser or homebar door	P ≤ 0.043AV+16.19
Refrigerator-freezer whose compensated cubic volume is no less than 500 L with ice-dispenser or homebar door	P ≤ 0.043AV+16.19 +2.6 (through-the-door ice dispenser) +0.022 (the length of the actual sealing perimeter of the homebar door of fresh compartment, cm) +0.036 (the length of the actual sealing perimeter of the homebar door of freezer compartment, cm)

<u>*A recent update of this standard includes two product classes over 1000L, due to the small market share and the standard specifications not being available for the analysis, we are omitting these classes.*</u>

Table A. 60.5 – Commercial Refrigerators Minimum Energy Performance Standard

73. Items	74. MEPS 75. From 1 January 2010
76. Refrigerator only	**77.** $P \leq 0.111AV+50.25$
78. Refrigerator-freezer	**79.** $P \leq 0.129AV+48.57$

Energy Efficiency Index Formulas

Split Room AC Efficiency Index

$$\cancel{EER =} EER = \frac{Measured\ Cooling\ Capacity\ [W]}{Measured\ Power\ Consumption\ [W]} \qquad \textbf{Equation A. 2}$$

Freezers

$$\cancel{R =} R = \frac{MEPS\ [kWh/month]}{Measured\ monthly\ power\ consumption\ [kWh/month]} \qquad \textbf{Equation A. 3}$$

Boilers

$$\cancel{R = Measured\ thermal\ efficiency\ for\ heating}$$

$$\cancel{(\%)} R = Measured\ thermal\ efficiency\ for\ heating\ [\%] \qquad \textbf{Equation A. 4}$$

Residential Refrigerator

$$R = \frac{MEPS\left[\frac{kWh}{month}\right]}{Measured\ monthly\ power\ consumtpion\ \left[\frac{kWh}{month}\right]} \cancel{R = \frac{MEPS\left[\frac{kWh}{month}\right]}{Measured\ monthly\ power\ consumtpion\ \left[\frac{kWh}{month}\right]}} \qquad \textbf{Equation A. 5}$$

Commercial Refrigerator

$$\cancel{R =} R = \frac{MEPS\ [kWh/month]}{Measured\ monthly\ power\ consumption\ [kWh/month]} \qquad \textbf{Equation A. 6}$$

80. Efficiency Level Tables

Table A. 80.1 Energy Efficiency Levels for Split Room Air Conditioner - RCC < 4.0 kW

81. R	**82.** Standby power **83.** (Off mode power consumption)	**84.** Level
4.36 ≤ R	≤ 1.0 W	**85.** 1
4.36 ≤ R	N/A	**86.** 2
4.00 ≤ R < 4.36	N/A	**87.** 3
3.67 ≤ R < 4.00	N/A	**88.** 4
3.37 ≤ R < 3.67	N/A	**89.** 5

Table A. 80.2 Energy Efficiency Levels for Split Room Air Conditioner - RCC < 4.0 kW with network function

R	Standby power	**90.** Level
4.36 ≤ R	≤ 1.0 W (off mode) **91.** ≤ 3.0 W (active standby mode)	**92.** 1
4.36 ≤ R	N/A	**93.** 2
4.00 ≤ R < 4.36	N/A	**94.** 3
3.67 ≤ R < 4.00	N/A	**95.** 4
3.37 ≤ R < 3.67	N/A	**96.** 5

Table A. 80.3 Energy Efficiency Levels for Split Room Air Conditioner - 4.0 kW ≤ RCC < 10.0 kW

97. R	**98.** Standby power **99.** (Off mode power consumption)	**100.** Level
4.40 ≤ R	≤ 1.0 W	**101.** 1
4.40 ≤ R	N/A	**102.** 2
3.86 ≤ R < 4.40	N/A	**103.** 3
3.39 ≤ R < 3.86	N/A	**104.** 4
2.97 ≤ R < 3.39	**105.** N/A	**106.** 5

Table A. 80.4 Energy Efficiency Levels for Split Room Air Conditioner - 4.0 kW ≤ RCC < 10.0 kW with network function

107.	**108.** tandby power	**109.** evel
4.40 ≤ R	≤ 1.0 W (off mode) **110.** ≤ 3.0 W (active standby mode)	**111.** 1
4.40 ≤ R	N/A	**112.** 2
3.86 ≤ R < 4.40	N/A	**113.** 3
3.39 ≤ R < 3.86	N/A	**114.** 4
2.97 ≤ R < 3.39	N/A	**115.** 5

Table A. 80.5 Energy Efficiency Levels for Split Room Air Conditioner - 10.0 kW ≤ RCC < 17.5 kW

116. R	**117.** Standby power **118.** (Off mode power consumption)	**119.** Level
4.62 ≤ R	≤ 1.0 W	**120.** 1
4.62 ≤ R	N/A	**121.** 2
3.89 ≤ R < 4.62	N/A	**122.** 3
3.28 ≤ R < 3.89	N/A	**123.** 4
2.76 ≤ R < 3.28	N/A	**124.** 5

Table A. 80.6 Energy Efficiency Levels for Split Room Air Conditioner - 10.0 kW ≤ RCC < 17.5 kW with network function

125. R	**126.** Standby power	**127.** Level
4.62 ≤ R	≤ 1.0 W (off mode) **128.** ≤ 3.0 W (active standby mode)	**129.** 1
4.62 ≤ R	N/A	**130.** 2

3.89 ≤ R < 4.62	N/A	**131.** 3
3.28 ≤ R < 3.89	N/A	**132.** 4
2.76 ≤ R < 3.28	N/A	**133.** 5

Table A. 80.7 Energy Efficiency Levels for Split Room Air Conditioner - 17.5 kW ≤ RCC < 23.0 kW

134. R	**135.** Standby power **136.** (Off mode power consumption)	**137.** Level
4.11 ≤ R	≤ 1.0 W	**138.** 1
4.11 ≤ R	N/A	**139.** 2
3.54 ≤ R < 4.11	N/A	**140.** 3
3.05 ≤ R < 3.54	N/A	**141.** 4
2.63 ≤ R < 3.05	N/A	**142.** 5

Table A. 80.8 Energy Efficiency Levels for Split Room Air Conditioner - 17.5 kW ≤ RCC < 23.0 kW with network function

143. R	**144.** Standby power	**145.** Level
4.11 ≤ R	≤ 1.0 W (off mode) **146.** ≤ 3.0 W (active standby mode)	**147.** 1
4.11 ≤ R	N/A	**148.** 2
3.54 ≤ R < 4.11	N/A	**149.** 3
3.05 ≤ R < 3.54	N/A	**150.** 4
2.63 ≤ R < 3.05	N/A	**151.** 5

Table A. 80.9 Energy Efficiency Levels for Freezers

152. R	**153.** Level
2.20 ≤ R	1
1.90 ≤ R < 2.20	2
1.60 ≤ R < 1.90	3
1.30 ≤ R < 1.60	4
1.00 ≤ R < 1.30	5

Table A. 80.10 Energy Efficiency Levels for Gas Boilers

154. R	**155.** Standby power **156.** (sleep mode)	**157.** Level
158. 87.0% ≤ R	**159.** ≤ 3.0W	**160.** 1
161. 85.0% ≤ R	**162.** N/A	**163.** 2
164. 83.0% ≤ R < 85.0%	**165.** N/A	**166.** 3
167. 81.5% ≤ R < 83.0%	**168.** N/A	**169.** 4
170. 80.0% ≤ R < 81.5%	**171.** N/A	**172.** 5

Table A. 80.11 Energy Efficiency Levels for Refrigerator-Freezer with Adjusted Volume Less than 500 Liters

173. R	**174.** Level
1.60 ≤ R	1
1.45 ≤ R < 1.60	2
1.30 ≤ R < 1.45	3

$1.15 \leq R < 1.30$	4
$1.00 \leq R < 1.15$	5

Table A. 80.12 Energy Efficiency Levels for Refrigerator-Freezer with Adjusted Volume Above 500 Liters

175. R	**176.** Level
1.90 ≤ R	1
1.75 ≤ R < 1.90	2
1.60 ≤ R < 1.75	3
1.45 ≤ R < 1.60	4
1.00 ≤ R < 1.45	5

Table A. 80.13 Energy Efficiency Levels for Commercial Refrigerators - Refrigerator only

177. R	**178.** Level
4.20 ≤ R	1
3.40 ≤ R < 4.20	2
2.60 ≤ R < 3.40	3
1.80 ≤ R < 2.60	4
1.00 ≤ R < 1.80	5

Table A. 80.14 Energy Efficiency Levels for Commercial Refrigerators-Freezers

179. R	**180.** Level
3.40 ≤ R	1
2.80 ≤ R < 3.40	2
2.20 ≤ R < 2.80	3
1.60 ≤ R < 2.20	4
1.00 ≤ R < 1.60	5

181. Unit Energy Consumption Calculation formulas

Split Room Air Conditioner UEC

$$UEC = \frac{Capacity\ [kW] \cancel{(kW)}}{EER\ \cancel{\left(\frac{W}{W}\right)} \left[\frac{W}{W}\right]} \times Annual\ Use \left[\frac{Hours}{Year}\right] \cancel{\left(\frac{Hours}{Year}\right)} \times Running\ Rate\ [\%] \cancel{(\%)}$$

Equation A. 7

Freezers UEC

$$\cancel{UEC =} UEC = \frac{MEPS\ [kWh/month] \times 12 [month/year]}{R[Energy\ Efficiency\ Index] \cancel{R\ (Energy\ Efficiency\ level\ index)}}$$

Equation A. 8

Boilers UEC

$$UEC = \frac{2.2593 \times HDD + 1666}{\left(\frac{EEI}{100}\right)}$$ [NDB48] [149] **Equation A. 9**

This formula is from Figure 19 of "Global Potential of Energy Efficiency Standards and Labeling Programs" by McNeil et al LBNL-760L.

Residential Refrigerators UEC

$$UEC = \frac{MEPS \cancel{(}[kWh\ per\ month] \cancel{kWh\ per\ month)}}{R \cancel{(}[Energy\ Efficiency\ Index] \cancel{Energy\ Efficiency\ Index)}} \times 12$$

Equation A. 10

Commercial Refrigerator UEC

$$UEC = \frac{MEPS\ [kWh/month] \times 12[month/year]}{\cancel{R\ (Energy\ Efficiency\ level\ IR}[Energy\ Efficiency\ Index]\cancel{ndex)}}$$ **Equation A. 11**

182. Tables of Assumptions

Table A. 182.1 – Assumptions for Calculating UEC for Room Air Conditioners

183. Group	**184.** Capacity	**185.** EER*	**186.** Annual Use	**187.** Running Rate	**188.** Reference
189. RCC < 4.0kW	**190.** 2375W	**191.** 3.37	**192.** 732	60%	(Choi, 2012a)
4.0kW ≤ RCC <7.5kW	5905W	2.97			
10.0kW ≤ RCC < 17.5kW	12320W	2.76			
17.5kW ≤ RCC < 23.0kW	19261W	2.63			

*UEC from level 2 to level 1 has a 3% increase; all EER levels are baseline number.

Table A. 182.2 – Assumptions for Calculating UEC for Freezers

193. Adjusted Volume	**194.** MEPS	**195.** R(baseline)
196. 438.6L	**197.** 44.7	**198.** 1

Table A. 182.3 Assumptions for Calculating UEC for Boilers

199. Heating Degree Days	**200.** EEI(baseline)
201. 2288 days/year	**202.** 80%

Table A. 182.4 – Assumptions for Calculating UEC for Residential Refrigerators

203. Group	**204.** Adjusted Volume	**205.** MEPS
206. Refrigerator only	**207.** NA	**208.** NA
209. Refrigerator-freezer whose compensated cubic volume is less than 500 L	**210.** 329L	**211.** 37.7
212. Refrigerator-freezer whose compensated cubic volume is no less than 500 L without ice-dispenser or homebar door	**213.** 1224	**214.** 68.8
215. Refrigerator-freezer whose compensated cubic volume is no less than 500 L with ice-dispenser or homebar door	**216.** NA	**217.** NA

Table A. 182.5 – Table of assumption in UEC for Commercial Refrigerators

218. Group	**219.** Adjusted Volume	**220.** MEPS	**221.** R (baseline)
222. Refrigerator only	**223.** 1023.7L	**224.** 163.88 (kWh/month)	**225.** 1
226. Refrigerator-Freezer	**227.** 1573.6L	**228.** 251(kWh/month)	**229.** 1